EFFECT OF HARVESTING SYSTEMS AND WILTING ON BERMUDAGRASS NUTRIENT RECOVERY AND NUTRIENT UTILIZATION BY BEEF CATTLE

BY

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1991

DEDICATION

To the memory of my father, El Hadji Hamidou Berthe, may god bless him and grant him peace.

To the memories of my beloved grandmother and Aunt, Bintou Coulibaly, Tenin Keita whose affection and guidance have given me determination to strive for progress.

To my mother Sanata Keita who showed me early the values of knowledge.

To my dear wife, Oumou Sidibe, whose support, dedication, patience and endurance has made possible the successful achievement of our Goal.

To my children, Abdramane, Bintou, Seydou, Hamidou, Ibrahim and Kadidia-- The future is yours!

ACKNOWLEDGMENTS

The complex nature of a beef/forage system analysis required collaboration and coordination from various people. Drs. William E. Kunkle and Douglas B. Bates served as chair and cochair, respectively, and are to be commended for their aid in organizing the project and for editing the manuscript. Their guidance and constructive criticism are appreciated. To Professors John E. Moore, Charles Staples and Thomas Spreen, a message of gratitude is conveyed for their able and willing participation. Special thanks are expressed to Dr. George E. Combs, graduate coordinator, for the time he devoted to me during my program. A note of thanks is extended to Angelita Mariano, Jeanette Filer, William Schwingel and Tadd Dawson for their support. The friendship and support offered by Dr. Sandra Russo, John Lichte, Dr. Della McMillan, Dr. Ester Smith and many people not cited here are greatly appreciated.

I am also thankful to Jerry Wasdin and his team at Pines Acres for all help in harvesting, storing and feeding the forages used in these experiments. The friendship and humor of Sandy, Dan and Tom made the social environment more tolerable.

The financial support of my program was provided by IER/USAID/SECID. The initial assistance of Dr. Thomas Fretz as training coordinator is appreciated. I am thankful to Dr. Irma Silva-Barbeau and Dr. Ruth Niles for their supports as training coordinator for the project IER/USAID Mali.

I am especially indebted to a group of individuals whose collaboration and help have certainly shaped the path of my life; the friendship of Dr. Tiomoko Traore, the teaching and support of Dr. N'Golo Traore, Dr. Abou Bagayoko, Ir. Mamadou Fatogoma Traore and Dr. J.H. Teissier are inestimable.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida on Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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By

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December 1991

Chairman: William E. Kunkle
Major Department: Animal Science

Delayed harvesting of forages lowers forage quality and increases supplemental feed costs. Harvesting-storing methods such as round bale silage offer potential to harvest tropical grasses at optimum maturity during periods of frequent rainfall.

Experiments 1 and 2 conducted in 1988 and 1989 evaluated the utilization of stored bermudagrass. A first cutting harvested after 5-6 weeks of regrowth in 1988 and 6-7 weeks of regrowth in 1989 was stored in polyethylene wrapped round bales. Treatments included harvesting immediately after cutting (unwilted), 1 to 2 hour wilt (1 to 2h-wilted), 2 to 4 hour wilt (2 to 4h-wilted) or 2 to 3 days of field-curing as hay. Storage losses were assessed using bale weight and gross energy content of 12 bales per treatment. The four treatments were offered ad libitum to 2 groups of 10 cattle each to evaluate intake and weight gain and to 6 sheep to determine digestibility.

Another cutting of bermudagrass harvested after 8 weeks of regrowth with treatments similar to those mentioned previously was also evaluated. The four treatments of bermudagrass were offered to 2 groups of 10 cows each to evaluate weight change, condition score change, evaluated. The four treatments of bermudagrass were offered to 2 groups of 10 cows each to evaluate weight change, condition score change, pregnancy rate and calf performance.

In experiment 1, gross energy recovery averaged 90% for all silages, but was higher (98%) for hay. Gross energy digestibility for unwilted, 1 to 2h-wilted and hay averaged 51%, but was lower for 2 to 4h-wilted (48%). Crude protein digestibility averaged 68% for wilted silages, but was lower for unwilted silage (63%) and hay (58%). In experiment 2, energy digestibility was similar and averaged 51% for all treatments. Crude protein digestibility was similar for wilted silages (averaging 57.7%) lower than that of unwilted silage (63.2%), but higher than that of hay which averaged 45.6%. Nitrogen retention was higher for hay (-0.29 g/day) and 2 to 4h-wilted silage (0.00 g/day) than for unwilted silage (-2.63 g/day).

In experiment 1, daily intake of heifers fed 2 to 4h-wilted and hay was similar and averaged 1.92% bodyweight (BW), but was less for 1 to 2h-wilted (1.84% BW) and unwilted (1.70% BW). Heifers fed the 2 to 4h-wilted gained 160 g/d in experiment 1 and 80 g/d in experiment 2. These gains were similar for cattle fed hay which gained 236 g/d and 32 g/d, but higher than 1 to 2h-wilted and unwilted which lost 70 and 0 g/d and 30 and 100 g/d in experiments 1 and 2, respectively. Intake of bermudagrass forages by cows ranged from 1.19 to 1.76% BW for unwilted, 1.41 to 1.89% BW for 1 to 2h-wilted, 1.53 to 1.93% BW for 2 to 4h-wilted and 1.53% to 1.86% BW for hay. Pregnancy rate and calf weaning weight were similar across treatments in both experiments.

CHAPTER I
INTRODUCTION

It certainly can be argued that animals are not essential sources of nutrients in human diets. Animals play fundamental ecological and economic roles, however, in the functioning of farm, regional, national and international food production and economic systems. They are the only economic and low cost energy means by which man can utilize vast areas of the earth which are unsuitable for cropping because of aridity, excessive rainfall, topography or soil type. The energy fixed by plant systems is largely contained in the structural carbohydrates, cellulose and hemicellulose. The diversity of anatomical and physiological adaptations of ruminant animals allows them to utilize many vegetational zones and contributes to man's material needs.

One major nutritional fact to which many ruminants must adapt is a seasonal rhythm in the availability of food. This is caused by higher or cooler temperatures in higher latitudes and rain or drought in lower latitudes. In both situations, abundant nutritious plant growth alternates with a period of low forage quality and availability. Therefore, the conservation of forage for the provision of dependable feed supplies is an essential feature of an efficient agriculture.

Haymaking is not a satisfactory process under tropical and subtropical conditions when optimum cutting dates coincide with high atmospheric humidity (Mott, 1981; Jarrige, 1982). Ensiling is less weather-dependent than haymaking and may allow the best use of a given land area. The general consensus is that silage made from tropical forages are at best medium to low in quality. Silage-making methods in the tropics and subtropics could benefit, however, from recent progress made in temperate areas.

Harvested forages offer the ability to establish feeding programs to maximize or optimize feed resources under existing farm conditions. A certain amount of data is available on the biological aspects of the conservation of warm-season grasses (Catchpoole and Henzell, 1971; Miller et al., 1967); however, little work has been carried out on the interplay between biological and nonbiological factors in terms of a system of forage production and utilization.

Many factors which limit the nutritive value must be overcome before the potential of grass silage is fully exploited as winter feed. The intake of silage may be lower than that of fresh or dried feeds from the same crop (Demarquilly, 1973; Campling, 1966; Harris and Raymond, 1963). The utilization of the nitrogen of silage may also be decreased (Waldo et al., 1966; Fatianoff et al., 1966).

The overall objective of this research was to address the question of whether or not harvesting bermudagrass at different levels of dry matter (DM) will improve the quality of silage made from tropical grasses. The specific objectives included the effect of wilting, harvesting/storing and feeding bermudagrass as round bale forages on intake, digestion and nutrient utilization by beef cattle.

CHAPTER II
LITERATURE REVIEW

Improved forage plants and cattle breeds have been developed in many subtropical and tropical countries. Because of seasonal fluctuations in forage production and quality, however, ruminant livestock are fed often at maintenance and submaintenance levels during winter or dry periods. Low levels of nutrition have been reported by numerous studies to limit production in cow-calf and stocker operations. Alternative winter nutritional managements based on strategic feeding to optimize the reproductive rate of the pregnant and lactating beef cow have been implemented as a result of research work. The application of these principles of management mainly at the level of small farmers is far from optimum, however. In most cases the socio-economic consequences of these new technologies have received little attention.

The use of chemically and biologically upgraded standing hay (Leng and Preston, 1976; Kunkle et al., 1984) or crop residues such as straws and other fibrous by-products as feed for beef cows has been reported. Supplements like forage sorghum, corn silage and concentrates have been also used, but these feeds may not be profitable in some situations. In addition, beef feeding systems based on high input technologies are inclined to be sensitive to changes in input prices. Most tropical and subtropical countries are deficient in grain production and must rely on the use of forage for beef cow production.

Dry Matter Production of Tropical Grasses

The growth of perennial tropical grasses is limited in many areas of the world by low temperatures (1 to 10°C) at higher elevations, lack of moisture and diminishing daylength. Lazenby (1982) showed that DM production increased with rate of nitrogen (N) and was reduced by frequent defoliation for both temperate and tropical grasses. Yields of tropical grasses were greater at the higher temperature range; however, the production of the temperate species was affected little by temperature. Only small differences existed in the nitrogen uptake of the grasses, but increasing temperature resulted in higher N recovery by tropical species and a lower recovery by the temperate species.

Several investigators have demonstrated inverse relationships between forage quality and temperature (Dirven and Deinum, 1977; Jolliff et al. 1979) under controlled conditions. Minson and McLeod (1970) showed that DM was negatively correlated with mean temperature and rate of evaporation. Weather conditions vary with season and year and have considerable effect on grass yields. In any year, however, the yield and nutritive value of the harvested grass are determined by the level of nitrogen use, maturity at first cutting, and frequency of cutting forage regrowth.

Prine and Burton (1956) and Burton and Jackson (1962) reported increases in bermudagrass yield with less frequent cutting with maximum production occurring at 6-week harvest frequency. Greatest crude protein (CP) yields and best recovery of N occurred with regrowth intervals of 6 to 8 weeks, however. Holt and Conrad (1984) evaluated several bermudagrass varieties at 3, 6, and 9 weeks harvesting frequencies over a 3-year period. Dry matter production ranged from about 12.4 tons/hectare (ha) for callie to nearly 18.5 tons/ha for coastal. They reported no additional increases in yield after a 6-week regrowth interval.

In another experiment, Holt and Conrad (1986) evaluated five cultivars of bermudagrass. The grasses were harvested at 2, 4, 6, and 8-week regrowth intervals over 2 two years to determine responses to harvest frequency and evaluate seasonal trends in digestibility. Total annual forage yield increased 0.15 Mg per hectare (ha) with increased regrowth intervals over 2 weeks. Total yields were 58% higher when harvested every 8 weeks compared to harvesting every 2 weeks. There was a tendency for the rate of increase in production to be less at the higher regrowth intervals, however. Digestibility declined with longer regrowth intervals. Based on the linear relationship between the decline in in vitro DM digestibility (IVDDM) and age (in days), IVDDM declined approximately 2 g/kg with advancing age. These results suggest that practical forage conservation systems represent a compromise between yield and quality, since both cannot maximized under any management strategy.

Reasonable prediction of DM yield and quality is required for an efficient use of the forage produced. Overman et al. (1988) developed a model which describes yield distribution and seasonal total yearly production of forage DM and protein. This model includes factors such as nitrogen level, harvest interval and moisture status. Cumulative yield from the beginning of the season up to any harvest is the sum of the individual harvests. The effects of N level and harvest interval on seasonal yields are given by the logistic equation (Rakowsky, 1983). An evaluation of the model consisted of demonstrating that normalized yield versus time are in agreement for field data from Watkinsville, Georgia; Tifton, Georgia; and Gainesville, Florida.

Overman and Angley (1989) showed that total seasonal yield is a linear function of fixed harvest interval. This last model can be used to compute the seasonal yield under a cutting regime for use in a forage conservation system analysis.

Conservation of Warm-Season Grasses

The major seasonal changes in the utilization of pasture forage plants are those associated with the availability of herbage and the maturation of the plant. Terry and Tilley (1964) showed that at early stages of growth, all parts of the grass plant are highly digestible, but that during stem elongation and flowering there is a more rapid decline in the digestibility of stem than of leaf. The digestibility of the sward is, therefore, determined by the maturity of its components and their relative proportions in the sward. This chiefly depends on the proportion of reproductive tillers which are permitted to flower by the intra-sward competition for light and harvesting regime. For maximum yields of highly digested, nutritious herbage, the sward must be maintained in a leafy condition, and this is usually best achieved by a system where close grazing or cutting alternates with suitable rest periods when fertilizers are applied. Attaining higher levels of production from forage sources requires conservation of grass to preserve quality. Forage conservation has been advocated to reduce losses of herbage due to senescence and decay and to maintaining a sward of high nutritive value for the whole season.

The usual method of conserving green forage plants for winter use is haymaking, but the losses of nutritive value in this process may be high (Watson et al. 1937). Hay making is not a satisfactory process under tropical and subtropical conditions when optimum cutting dates coincide with frequent rains and high humidity (Mott, 1981; Jarrige, 1982). Artificially dried forages, on the other hand, are completely independent of the weather and provide a product of high quality. They require a substantial capital investment in machinery, equipment and fuel costs.

Silage making has, as its main advantage, the ability to conserve high yields of grass with relatively low vulnerability to weather. The greater bulk of material involved, as opposed to hay and dried grass, causes feeding/handling problems, however. In addition, the final product may show a wide variation in composition and nutritive value according to the stage of maturity and the fermentation process.

It is possible to improve the suitability of the forage cut for conservation through wilting and/or the use of additives. Good silage made by any method is a valuable feedstuff (Watson, 1939) and will not differ markedly in composition from the original crop. For a winter feeding system utilizing conserved forage, requirements for supplements will depend upon the quality of silage. The nutrient concentration of silage is as good or better than that of hay (Waldo, 1977), but the voluntary intake of silage may be less than that of the fresh forage (Harris and Raymond, 1963) or hay (Campling, 1966).

Conventional silage making has been associated with high costs of machinery and storage facilities. The high capital investment of these systems has prevented small farmers from using silage systems for winter feeding. The introduction of new management techniques such as harvesting/storing and feeding systems using bagged or plastic wrapped high moisture forages are less capital intensive alternatives for conserving and feeding silage on small farms. More research is required to understand the biological (nutrient recovery and quality) and non-biological constraints (returns over feed costs) of these new systems.

Some researchers have concluded that round bale conditions are not suitable for an efficient fermentation (Anderson et al., 1985) because of air leaks in addition to the long stems which tend to reduce the density of bales. The fundamental conditions required for the effective preservation of silage (i.e., anaerobic storage, high density and low pH) are difficult to achieve in round bale silage. Because the herbage is not chopped, the release of nutrients necessary for lactic acid fermentation is restricted. The crimped grass is rolled which does not give the bale a high density as compared to bales made with chopped grass. Finally, the polyethylene bag is partially permeable to oxygen and sensitive to mechanical damage. A high pH, low concentration of organic acids, and the presence of oxygen in silage favor the growth of deteriorating bacteria, such as clostridia , facultative _Bacillus_ species and enterobacteria (Woolford, 1984; Lindgren et al., 1985) and even pathogenic bacteria like _Clostridium botulinum_ and _Listeria monocytogenes_ (Ricketts et al., 1984). The proper concentration of moisture at baling is still controversial, but 50% to 60% has been suggested to be desirable by a number of authors (McDonald, 1981; Woolford, 1984). Research workers at the University of Florida (Bates et al. 1989a) reported that round bale silage made from tropical forages produced both good and bad preserved silage. Much less is known about these systems in terms of animal production and efficiency of utilization of resources at the farm level, however.

Silage-Making Systems

Good silage is the product of a process whereby lactic acid bacteria ferment sugars of forage plants to lactic acid and the growth of competing microorganisms, especially enterobacteria and clostridia, are inhibited. Bacterial growth is controlled by the acidity and by the osmotic pressure of silage. The major substrate for anaerobic fermentation is sugar or water-soluble carbohydrates (WSC) which are fermented to organic acids (McDonald et al. 1973). The major organic acids (citrate, malate and glycerate) can be fermented by lactic acid bacteria. The effectiveness of the acids resulting from the growth of lactic acid bacteria in reducing the pH is primarily dependent on the buffering capacity of the initial ensiled forage plant.

Considerable research has been made into the ensiling process, however, defining the exact conditions required to produce a stable end-product or to predict accurately the nutritive value of silage remains a challenge. Whittenbury et al. (1967) stressed that the rate of decline in pH is of greater importance than the final pH attained. Rapid acidification reduces the risk of early growth of clostridia (Van Beynum and Pette, 1936). It inhibits the growth of other undesirable microorganisms and also post-harvest changes which are detrimental to silage quality.

The relation between sugar concentration and buffering capacity often determines the type of fermentation. During the ensiling of warm-season grasses and forage legumes that are characterized by low WSC concentration and high buffering capacity, enough lactic acid will not be produced to lower pH to the extent required for a stable product (4 to 4.2). Crops with higher buffering capacity require higher greater acid production to reach the pH required for good conservation. Consequently, a higher level of WSC will be required to produce higher levels of lactic acid. Zubrilin and Mischustin (1958) proposed the concept of minimum sugar, and Weissbach et al. (1974) suggested the ratio of sugar concentration to buffering capacity to characterize the acidification potential of a plant material. Wieringa (1958) has shown that the critical pH value for the growth of clostridia depends on the osmotic pressure (water activity) of the fermentating forage. With decreasing water activity, the sensitivity to acidity of these bacteria increased. As a consequence, the critical pH value is related to the DM concentration of the plant material. Wieringa (1969) described the relationship between pH and DM that separated stable silage from unstable silage. Stable silages occur if

$$\%DM \geq 25(pH) - 80$$

and unstable silages occur if

$$\%DM < 25(pH) - 80.$$

For example, silages at 20% DM are stable when pH < 4.0, but silages at 35% DM are stable when pH < 4.6.

Weissbach et al. (1974) recommended using the following equation:

$$F = d + 8Z/P_k$$

as a guide to predict the type of fermentation; where d=DM concentration and Z/P_k = ratio of WSC to buffering capacity. As the ratio of WSC to buffering capacity decreased, the minimum DM required to achieve satisfactory fermentation increased. The highest ratio was found to be for forage maize, while legume crops, particularly Medicago sativa, had the lowest ratio and were only likely to ferment satisfactorily when wilted to more than 30 percent DM prior to ensiling. This model also implies that making of good corn silage will be easy, making good grass silage will be intermediately difficult, and making good legume silage will be difficult.

Tropical grasses and forage legumes have low WSC (Catchpoole and Henzell, 1971; Wilson and Ford, 1973; Noble and Lowe, 1974) and high buffering capacity and require high concentrations of DM for a good fermentation. These authors reported WSC concentrations ranging from 2.5 to 9.9 percent of the DM in tropical legumes. Tosi et al. (1975) reported values of WSC as percentage of fresh weight of 3.67 and 1.74 respectively for Pennisetum purpureum and Panicum maximum. The DM concentration of these grasses were respectively 29.1 and 27.8 percent.

Wilkinson (1981) suggested that a concentration of 3 percent of WSC in the fresh crop for good preservation is largely applicable for both warm-season and cool-season grasses. Pennisetum purpureum and Digitaria decumbens have been reported to have higher concentrations of WSC than other tropical grasses (Tosi, 1973). Considerable variation exists in the sugar concentration of different crops, and also between grasses grown under differing conditions. It was reported that in bright, sunny weather the sugar concentration of grass was much higher than under cloudy, overcast conditions. A seasonal effect on the sugar concentration of grass cut at frequent intervals also has been reported, with less WSC being present in the latter part of the year than in early summer (Waite and Boyd, 1953). It is possible this effect may be an influence of weather. Mackenzie and Wylam (1957) reported that length of cutting interval did not influence sugar concentration. Waite and Boyd (1953) reported that high rate of fertilizer application decreased the concentration of WSC in the grass.

The type of fermentation in silage is dependent on the type and number of bacteria present on the herbage, the conditions created by the herbage in the silo and the ensiling technique. An adequate population of lactobacilli must be present on the herbage when it is ensiled to ensure quality silage. There is evidence of wide variation in the number of lactobacilli present on herbage (Stirling, 1953). Proteolytic bacteria must be kept to a minimum by avoiding contamination with soil.

The breakdown of cells and the consequent release of cell juices is regarded to be a necessary prerequisite for a rapid lactic acid fermentation. The acidifying effect of products formed when substrate in damaged plant cells is fermented is particularly important for the rate of release of plant cell juices. These acids start the autolysis at different rates depending on species, probably because of different structures. Alfalfa and orchardgrass have a slower plasmolysis than ryegrass (Greenhill, 1964; Wilson, 1984). Greenhill (1964) also reported that the infiltration of even small amounts of oxygen considerably delayed both plasmolysis and the start of pH reduction. Mechanical treatment, like chopping, favors consolidation and thus indirectly promotes the release of cell juices and desirable growth of lactic acid bacteria (Weise, 1968).

Additive-based silage systems

McDonald et al. (1973) concluded that in forages with less than 15% DM, the moisture invariably counteracts the preservative effects of the primary fermentation acids, and clostridia may not be suppressed at a pH as low as 4. Clostridia have been reported to tolerate high concentrations of acids in environments where water is freely available. The weather conditions prior to harvest and grass species are important factors affecting DM concentration. Legume forage plants have a lower DM concentration than grasses at the same stage of growth. Nitrogen fertilizer application will also reduce the DM concentration and in the early stages of growth, the concentration of DM is also lower (Sprague and Taylor, 1970). In wetter climates, it is hard to obtain consistently good silages from young grass or legumes without the use of additives. As early as 1917, Lamb (1917) treated maize with chloroform, toluene, and cresol in an attempt to inhibit bacterial growth and preserve the maize in its original state. In 1926, Virtanen (1933) acidified grass by treating it with a mixture of sulphuric acid and hydrochloric acids and in 1937, Allen et al. (1937) investigated the effect of the addition of a solution of molasses inoculated with lactobacillii on DM recovery, chemical composition, and digestibility of grass silage. The integration of additives into farming systems started when applicators attached to the forage harvesters became available.

Many types of acids have been used as silage additives, based on the theory that direct acidification of the mass is a more certain method of preservation than relying on bacterial fermentation. Chemical additives used as fermentation inhibitors include both mineral and organic acids, salts of acids, formaldehyde and other aldehydes. Good results have been obtained with several acids (Breirem and Ulvesli, 1960), but more data have been published on the use of formic acid (85 per cent W/W) than on any other additive. Formic acid is a weaker acid than are mineral acids. The antibacterial action of formic acid and other acids is due both to a hydrogen ion concentration effect and to a selective bactericidal action of the undissociated acid. Woolford (1984) concluded that formic acid was more effective at inhibiting bacterial growth at pH 4, but at pH 5 to 6 propionic acid was more effective at inhibiting the growth of clostridia, Bacillus sp. and gram negative bacteria. Waldo (1978) reviewed the literature concerning the effect of formic acid on the nutritive value of silages and concluded that this additive has a beneficial effect on animal performance. Formaldehyde reduces proteolysis and rumen degradability and, when combined with an acid such as formic acid, it is an effective additive which reduces ammonia production and inhibits yeast growth (Hinks et al., 1980).

Sulfuric acid has gained in popularity in some countries. Flynn (1988) found that sulphuric acid (45 per cent W/W) fortified with copper had similar effects to formic acid in every parameter recorded. Acids are a hazard on the farm, however, and are corrosive to machinery. Salts of acids are safer to handle but are less effective than the acid from which they are derived. The hazardous nature of many chemical additives has persuaded many farmers to turn to additives which are fermentation stimulants. Fermentation stimulants include sugar sources (molasses, whey), dried concentrates, enzymes to convert storage or structural carbohydrate to WSC and inoculants containing lactic acid producing bacteria.

Biological additives such as enzymes and inoculants offer the advantage of being noncorrosive when compared to conventional acids or acid mixtures. Inoculants increase the concentration of lactic acid bacteria available for fermentation and contain one or more species of lactic acid bacteria, often with the addition of nutrients. Enzymes often include crude cellulases, hemicellulases and amylases that digest cellulose, hemicellulose and starch, respectively, during ensiling thereby increasing available sugar supply.

Several studies have shown the benefits of using inoculants containing homofermentative lactic acid bacteria as silage additives on a laboratory scale and on a farm scale (Woolford, 1984; McDonald, 1981). It is often difficult to separate the effects on fermentation due to DM and WSC from those due to added inoculants, however. Also, results of studies carried out in northern Europe with low DM grasses are not directly comparable with those carried out in the USA where high DM maize, sorghum and alfalfa are the principal crops ensiled. Inoculants containing Lactobacillus plantarum and Pediococcus acidilactici have generally been shown to be the most effective types of inoculants provided that at least 10^5 (but preferably 10^6) bacteria are added/g forage. Rooke et al. (1988) reported that even at very low WSC concentrations Lactobacillus plantarum improved silage fermentation. The degree of improvement was affected principally by crop WSC concentration, but delayed sealing of the silos and the addition of ammonium nitrate at ensiling affected the silage fermentation. Rooke et al. (1988) have shown that Lactobacillus plantarum can produce acetate from lactate at pH 4.5 coupled with the reduction of nitrate to ammonia in vitro. Lactobacillus plantarum has been shown to be able to regenerate NAD if oxygen is available by using NADH:H_2O oxidase or pyruvate oxidase (Condon, 1987). The same author suggests that to establish conditions in which silage inoculants can be tested rigorously, the primary determinant should be low crop WSC concentrations. Lindgren et al. (1988) shaded grass to reduce WSC concentrations, and Rooke et al. (1988) using a similar approach in recent studies has produced conditions in which an inoculant can fail. Inoculants have been found to benefit the silage fermentation of high DM crops but are often less effective on low DM crops, especially those with low WSC concentrations. Several studies have shown that if sugar is a limiting factor, then the lactic bacteria inoculants will not be able to produce enough lactic acid to lower the pH to a stable level.

There is a need for more research on the use of inoculants as silage additives for use with tropical grasses and forage legumes that are characterized by a low concentration of WSC. Dawson (1989) reported that the use of inoculants on bermudagrass preserved as round bale silage improved the ensiling fermentation early in the ensiling process as evidenced by higher Flieg scores and lowered yeasts and mold at day 5 and day 14. Inoculation with homofermentative lactobacilli did not result in substantially better round bale bermudagrass silage because the final pH of the silage was well above 4.2 and not low enough to inhibit secondary fermentation.

Wilted silage systems

Dutch workers indicated that the higher osmotic pressure in wilted silages had an inhibitory effect on proteolytic bacteria, and this explained the better preservation of wilted silage (Wieringa, 1960). The extent of fermentation is highly influenced by the DM concentration of the silage. At DM concentrations exceeding 35%, clostridia are inhibited by a lack of moisture whereas the lactic bacteria are able to grow, but at slow rate. At DM concentrations ranging from 15 to 35%, clostridia are inhibited by a combined effect of acidity and moisture availability. Wilting can lead also to a substantial decline in the numbers of facultative anaerobic endospore-forming bacteria, both on the crop and in silage.

Wieringa (1960) suggested that to guarantee the total suppression of clostridia a DM concentration in the region of 45 to 50% was required. However, at these high concentrations of DM, advantages in reducing fermentation losses may be offset by losses of DM from oxidation. Lanigan (1961) suggested that DM concentrations favorable to the silage fermentation are in the range of 20 to 25% and at levels above 33% no undesirable microbial activity will occur.

Lactic acid bacteria have been reported to tolerate low moisture availability (Lanigan 1961). Wilted grass silage containing 49% DM supported lower populations of lactobacilli and proteolytic bacteria and contained fewer fermentation acids than the corresponding direct-cut silage containing 19% DM. McDonald et al. (1968) reported similar trends with respect to fermentation acids and an increase in residual WSC with increase in silage DM concentration. Stone et al. (1944) showed that lactic acid bacteria can dominate the microflora of alfalfa silage containing 70% DM.

Silage made from tropical grasses has been reported to contain high concentrations of acetic acid (Miller, 1968; Catchpoole and Williams, 1969). Catchpoole (1970) and Wilkinson et al. (1983) suggested a rapid field wilting of tropical grasses prior to harvesting to reduce risk of secondary fermentation and decrease the proliferation of heterofermentative lactic acid producing bacteria. Wilting of grasses, in addition to restricting fermentation, reduces or eliminates seepage (Murdoch, 1960; Steensburg, 1952; Woodward and Shepherd, 1938). Advantages in reducing seepage may be offset when an appreciable amount of waste occurs as a result of difficulty in consolidating the wilted herbage, however (Murdoch, 1960). The degree to which the herbage should be wilted depends to some extent on the type of silo in which the silage is to be stored, because the drier the herbage becomes, the more difficult it is to consolidate. Herbage of 40% DM has been stored successfully in bunker silos, but generally it is less risky to aim at a DM concentration in the range of 30 to 35%. Herbage with higher DM concentrations can be stored successfully in tower silos (Murdoch et al., 1958). Livingstone (1988) suggested that herbage can be stored successfully as round bale silage within a range of moisture levels between 50 and 70%.

The wilting process is weather-dependent and the requirements for wilted silages are much the same as for haymaking. An extended wilting period as a result of rain falling on the herbage will increase losses during field drying. Weathering of the forage crop during the wilting period may have a marked effect on the quality of the silage by leaching of the nutrients (Morrison and Moore, 1954). Gains in weight of DM have been reported (Nash, 1959), and this may be related to photosynthesis after the grass is cut. Generally, however, field losses may be outweighed by lower losses during the fermentation process.

Wilted silages improve the economic efficiency of silos because greater quantities of DM can be stored; wilting causes a reduction in crop weight and fewer man-hours are required for transporting loads to the silo and making and utilizing silage.

Nutrient Losses during Harvesting

Respiration Losses

Nutrient losses at harvesting depend upon the length of field-curing and weather conditions which include radiation, rainfall, dry bulb temperature, relative humidity and wind speed. The drying pattern of plant material is affected by crop yield, stage of growth and leaf to stem ratio. The thickness of the swath which acts as a barrier to the removal of water loss from plant tissue will affect also the magnitude of losses. Types of harvesting losses in ensiled forage crops are not different from that of hay. Losses are due to plant respiration, leaching by rain, and mechanical treatments. The data reported in the literature may provide information for losses in these categories or information about the sum of two or even all three categories. Field losses that occur in the making of grass silage from unwilted crops are limited to nonmechanical and mechanical losses (scattered material). Non-mechanical losses are due to the respiration of plants, microbial decomposition and leaching by the rain. After the grass is cut, respiration continues until it is inhibited either by anaerobic conditions in the silo or by plant moisture levels.

There is a general agreement in the literature that the main respiratory substrates are plant sugar or WSC and, that the oxidation of "hexose" sugar is the basis of respiratory reaction. Overvest (1977) reported a gain in DM during short periods of wilting; he attributed this to continuing photosynthesis after cutting which offset the DM loss due to respiration. Pizzaro and James (1972) argued that this is unlikely since radiation within the appropriate wavelength limits only penetrates a thin layer of the swath.

Scottish Agricultural College researchers (SAC, 1979) suggested that degradation of protein to amino acids occurs during respiration. The feed value of amino acids for ruminants is similar to the original protein, but amino acids are more soluble and susceptible to leaching loss. No values were provided to quantify this effect, however.

Wood and Parker (1971) carried out laboratory experiments to simulate respiratory losses for barn dried hay. They measured the rate of CO_2 production over a period of 30 h from small samples of short cut ryegrass, each held in the dark at constant moisture (in the range of 27 to 85% moisture) and temperature (in the range 25 to 45°C). They observed higher respiratory rates at higher temperatures and higher moisture concentrations but little increase with temperatures above 25°C. A higher respiratory rate with less mature grass crops was also apparent in their results (McGechan, 1989). Parkes and Grieg (1974) measured CO_2 production and loss of DM in small samples of perennial ryegrass each held at constant temperatures (20 to 30°C) and moisture concentration (35 to 71%). They observed a decline in rate of respiration over a period of 120 h from an initial value similar to that found by Wood and Parker (1971). No measurement of WSC concentration at any stage was provided; however, this decline in rate of respiration could be attributed to depletion of substrate.

Pizzaro and James (1972) carried out experiments with simulated swaths consisting of small samples of perennial ryegrass in a greenhouse. They measured CO_2 produced and WSC concentration at various stages of growth and grass moisture concentration. They noted an increase in WSC concentration as crops matured, similar to that observed by Henderson and McDonald (1975). Respiration rates were higher for the less mature crops despite their lower WSC concentrations.

Melvin and Simpson (1963) measured respiration in terms of oxygen uptake and CO_2 production with small samples of ryegrass held in the dark. They observed faster respiration rates with less mature crops and a decline in rate of respiration over a 120 h period which was particularly marked for the least mature crop samples. Honig (1976) measured CO_2 production taken at 4 to 6 h intervals from small samples of grass from a swath drying in the field; respiratory rates were determined at the temperature and moisture content prevailing in the field. Respiratory rates increased almost linearly with temperature and quadratically with moisture content. Clark (1974) measured the respiratory rate during wilting with segments of grass leaves under controlled laboratory conditions. The rate of loss of DM, expressed per area of leaf surface, varied with moisture content. Pizzaro and James (1972) observed that if partly dried swaths were rewetted, the respiratory rate increased back to the level of the initial grass, while Honig (1979) observed an increase in respiratory activity when field swaths remained at high moisture concentrations due to rainfall.

Bastiman and Altman (1985) reported field losses averaging 4.8% for wilted silage by comparing yields of direct cut and wilted treatment cut on the same day; since most wilting took place on rain-free days, and no mechanical treatments were applied, this was most likely respiratory loss.

Schollhorn and Szokolai (1979) measured losses during barn drying experiments with three different temperatures regimes. The DM losses ranged from 3 to 4%, but losses of CP were 6 to 8%. Sweetman et al. (1950) reported field losses of 1% of the DM when a mixed crop of oats and peas was ensiled in 1948 without wilting, and field losses were 4.5% of the DM when a similar crop was ensiled in 1949 by wilting the crop in the field from 78% moisture to 70%. It cannot be implied, however, that wilting caused the difference from one year to another. Turk et al. (1951) reported field losses of 7.7 percent DM in 1947 and 8.5% DM in 1948 for mixed timothy-grass forage. Part of the field losses was attributed to the loss of forage spilled on the ground when the field chopper was turning corners. Rainfall after cutting forage will increase losses. Murdoch and Bare (1963) used sprinkler irrigation to simulate a 1.14-cm rain on curing meadow fescue and timothy; this treatment increased CP and nitrogen free extract losses by over 50%, but had no effect on DM losses. Guilbert and Mead (1931) used three lots of bur clover hay which had received no rain, 0.79 cm rain, or 1.98 cm rain during field curing. Total digestible nutrient concentrations were 62, 56, and 54% and digestible protein concentrations were 13.1, 11.8, and 11.4%, respectively. Shepherd et al. (1954) suggested that rain resulted in the loss of 20 to 40% of the DM, 20% of the CP, and 35% of the nitrogen free extract from curing legumes. Hart and Burton (1967) studied moisture losses and changes in yield and quality of 64 lots of coastal bermudagrass hay during field curing. Water concentration of grass after a day of curing was influenced by initial water concentration, vapor pressure deficit of the air, solar radiation, and yield; there was a significant interaction of initial water concentration with the other three factors. Water concentration of the grass might have decreased or increased during the night, depending upon water concentration at the end of the previous day, vapor pressure deficit and yield. Dry matter losses from hay yielding 2 MT/ha were 3.0% in dry weather and 9.6% when 5 mm of rain fell; losses from hay yielding 10 MT/ha were 4.6% and 11.1%, respectively. Dry matter, CP and digestible DM concentration decreased slightly in good curing weather and sharply in rainy weather. Carotene losses were higher when total radiation received during curing was higher. These authors concluded that rain during curing would produce greater losses in quality than delaying harvest until better weather was predicted.

Leaching losses have been measured in the laboratory by adding simulated rainfall to the samples (Fleischmann, 1912). Dernedde and Wilmschen (1969) used a sample of fully cured hay which was rewet by 10 ml of water from sprinklers and then allowed to dry under good or bad simulated weather conditions. By analyzing the water which ran off, they measured DM losses of 1% due to leaching for hay made from untreated grass and 2% for hay made from lacerated grass. Total losses during wetting and drying, which included respiratory loss, were in the range of 4 to 16%.

The sum of respiratory and leaching losses under a wide range of weather conditions has been reported by many scientists (Watson and Nash, 1960; Kormos and Chesnutt, 1967; Rucker and Knabe, 1983). Rucker and Knabe (1983) summarized their results by a regression equation which predicted a loss of about 2.6% as a result of 10 mm of total rainfall. Spencer et al. (1988) reported mean values of 3.2% for both respiratory and leaching losses which were estimated by comparing yield at cutting and harvest. These trials lasted 3 days under conditions of heavy rainfall with no mechanical treatments. In all of these studies, the increase in total loss during rainy compared with rain-free conditions included a higher level of respiratory losses and leaching losses at higher moisture concentrations. Pitt and McGechan (1987) showed that no runoff took place until the surface moisture was 1.2 times the mass of DM. They suggested that no leaching loss takes place with light rain.

In order to predict nonmechanical field losses, many models have been developed. Wood and Parker (1971) suggested the following relationship for respiratory loss at different temperatures and moisture concentrations:

$$R=0.177(0.056m-1.53)e^{0.069T}$$

where m = moisture concentration and T= temperature.
This equation has been reported to give levels of loss similar to field data for alfalfa (Wilkinson and Hall, 1960) and for ryegrass, clover and lucerne (Greenhill, 1959). Audsley (1986) cited by McGechan (1989) suggested another formula which he considers to be a closer fit to Wood and Parker's experimental data, and which includes a nonlinearity in the relationship to moisture concentration:

$$R=0.177(10e^{0.0051m}-11.53)e^{0.069T}$$

Parke et al. (1978) concluded that field respiratory losses follow Wood and Parker's formula, with T equal to the ambient temperature for forage in swaths, 5°C above ambient for hay bales in the field and 2°C above ambient for hay dried in the barn. Savoie and Marcoux (1985) and Rotz et al. (1989) also assumed respiratory losses according to the Wood and Parker formula. Rees (1982) compared the relationship between rate of respiratory loss and temperature and moisture concentration reported by

Wood and Parker (1971), Ohm (1972) and Honig (1979). He suggested a single relationship, including a linear relationship with temperature and a nonlinear relationship with moisture concentration:

$$R=T(0.000027m^2-0.00124m+0.0223)$$

He found very similar levels of respiratory loss during drying of hay from 80% to 23% moisture, although a linear relationship between moisture concentration and time over a period of 90 h was assumed in his calculation. McGechan (1988) using a similar calculation for a silage wilted from 80% to 70% moisture over 18.7 h observed less close agreement, especially at the lowest temperature. He proposed the following equation to fit Honig's data:

$$L_r=a\left\{\frac{Q}{K_m+Q}\right\}\{1-0.01b(D_e-D_c)\}e^{0.069T}(0.000128m^2-0.00588m+0.106),$$

This model based on Honig's data shows a nonlinear relationship of respiratory loss with temperature (Wood and Parker, 1971) and with moisture concentration. These data included measurements taken soon after cutting. With a = 0.1, D_c = De, b = 0.05 and K_m = 1% , this model is in agreement with laboratory studies. Field studies confirmed that the proposed model gives losses of the right magnitude.

Relationships to represent leaching losses are very limited because of limited experimental information. Parke et al. (1978) assumed the following relationship for leaching loss:

$$L_l=ar\left(\frac{90-m}{700}\right)$$

This was based on the value of 1% DM loss of material with a moisture concentration of 20% measured by Dernedde and Wilmschen (1969) with lower levels of moisture and at high moisture concentrations based on the work by Fleischman (1912). Hadders (1986) in a model of field drying of hay, assumed the following equation for losses due to rain:

$$L_l=\frac{r}{20}\left\{1-\frac{55}{(M+5)}+\frac{5.75}{(M+5)^2}\right\}$$

where

L_l = leaching losses, % DM.

r = amount of rain, mm.

M = moisture concentration of swath, %.

Savoie and Marcoux (1985) and Rotz et al. (1989) developed the following equation to predict leaching loss for alfalfa, based on the work of Collins (1985) and Fonnesbeck et al. (1982) and with no variation in moisture concentration:

$$L_l=Q_n(1-e^{-0.0011r})$$

Where

Q_n = 1-neutral detergent fiber (NDF) concentration.

r = amount of rain, mm.

Based on simulation tests using the model of Parke et al. (1978) for leaching loss, this equation gave very low values of leaching losses relative to other categories of losses. McGechan (1989) proposed the use of the model of Parke et al. (1978) for leaching loss multiplied by a factor of 10, but based on runoff rainfall rather than incoming rainfall.

Mechanical Losses

Losses also occur during mechanical operations i.e., mowing, spreading, tedding, turning or windrowing and pick-up. Losses occur when fragments of crop material become detached and blow away or drop into the stubble so that they are not picked up by the baler or forage harvester. As grass dries, it becomes more brittle and its susceptibility to this type of loss rises sharply. There is a variability in the severity of handling the forage which causes these losses to vary between different mechanical operations and between different machines for the same operation (Klinner, 1975). In some operations, such as tedding of swaths, tractor wheels run over the drying crop, while in others, such as turning windrowed swaths, they do not; further variations in loss level between operations therefore arise.

Laboratory studies can give an indication of the susceptibility of forage material to losses during mechanical operations in relation to factors such as DM concentration, grass variety or stage of maturity. Vincent (1983) carried out stress-strain experiments to determine the stiffness and fracture properties of individual grass leaves over a range of moisture concentrations. Stiffness increased markedly as the moisture concentration dropped below 50%, with a further steep rise in stiffness as the moisture concentration dropped below 20%. A comparison of changes in stiffness in transverse and longitudinal directions indicated that a change in stiffness of the cells between the fibers, rather than the fibers themselves, accounted for changes in properties of grass material with moisture concentration.

McGechan (1988) studied losses for samples being dried on a laboratory thin layer drying apparatus. Four experiments were carried out on several cuttings and on two maturities forage with perennial ryegrass as the predominant species in the silage and hay. In the later experiments, some samples were conditioned at cutting while some were not. A simulated "tedding" treatment was carried out by hand on each sample at intervals during the drying process, and loss of material was determined. Results with first cut crops showed a low level of loss per tedding until a break-point moisture concentration of about 45% was reached, after which loss levels rose very sharply. Low levels of loss rose even more steeply, and the breakpoint occurred at slightly higher moisture concentrations with more mature crops. Savoie et al. (1986) in laboratory experiments of field tedding with timothy grass reported a pattern similar to that shown by McGechan (1988).

Honig (1979) studied pick-up losses such as occur with a baler or forage harvester fitted with a conventional tine pick-up reel. Pick-up was simulated by removing the bulk of the material with a hand fork operating in the direction a full scale machine would work. Raking was performed four times at right angles to the machine working direction, and material regarded as pick-up loss was weighed. Losses varied in the range 0.2 to 0.5 t DM/ha, depending mainly on the setting of the machine. Overvest and Schukking (1974) raked up hay left by a loader wagon with a tine pick-up; these losses averaged about 1.5%.

Klinner and Wood (1981) measured losses with different pick-up systems by raking up the lost material from the stubble. For a conventional tine pick-up, losses were roughly 1% and were independent of throughput with a scrambled crop after cutting with a mower conditioner or after windrowing. For a crop remaining undisturbed after cutting with a drum mower with no conditioner, however, the grass was oriented in the direction of travel, and losses increased with throughput. They developed an experimental alternative pick-up system using nylon brushes instead of steel tines. With this system, pick-up losses were reduced to about 0.4% for a scrambled crop or about 0.8% for an unconditioned undisturbed mown crop. Mayne and Gordon (1986a) raked up lost material after pick-up by a forage harvester. Losses ranged from 0.9 to 3.7% (0.04 to 0.14 t DM/ha) with a precision chop harvester and were affected by cutting and extent of wilting. Losses in the range 0.7 to 1.1% (0.03 to 0.04 t DM/ha) were found with a flail harvester cutting and picking up in a single operation.

Small and Gordon (1988) evaluated field losses from four systems of harvesting grass for silage. These systems were: single-chop flail harvester direct cutting (SCD); double-chop flail harvester direct cutting (DCD); mown with a rotary mower and picked up with a precision-chop harvester either immediately (PCU) or after wilting until the DM-content had increased by approximately 10% (PCW). At each harvest, and in total over the season, the total field losses of organic matter (OM) were greater with the PCU and PCW treatments than with the SCD and DCD treatments. The field losses 4.1 and 6.5% observed with the PCU and PCW treatments are similar to the total field losses of 4.4 and 6.6%

reported by Mayne and Gordon (1986a) using similar treatments. However, these losses are very likely to be an underestimation of the actual losses that occurred due to grass growth which would have occurred between assessing the available yield and the actual harvesting operations. Spencer et al. (1989), in an experiment into alternative swath treatments for silage wilting, reported wide variations between samples as well as between treatments. Average pick-up losses were 0.071 t DM/ha (0.6%) after wilting in an undisturbed mower conditioned windrow covering about half the stubble area, 0.126 t DM/ha (1.2%) after wilting in a spread swath with regular tedding and rowing up before baling, and 0.163 t DM/ha (1.5%) after wilting in a windrow with regular turning. The high level of loss with the last treatment arose because the crude swath turner used tended to displace some material to the side of the windrow where it was missed by the baler pick-up reel.

Savoie (1988a) measured shattering losses in timothy grass crop after tedding swaths once by gently displacing the tedded windrow with a pitch-fork and then hand picking the broken forage material over an area 1 m long by one mower width; only material shorter in length than 200 mm was regarded as shatter loss. Part of the shatter loss was attributed to the mowing operation, and the shatter loss during tedding, calculated by comparing losses in tedded and untedded windrows, was only 0.1 to 0.2%.

Honig (1976) reported cutting losses in the range 0.2 to 0.5 t DM/ha with drum or disc mowers and mower conditioners. Savoie (1988b) observed losses of 0.7 to 1.9% after mowing timothy, but the mower was fitted with a rubber roll conditioning system. Klinner et al. (1975)

measured both baled and raked yields for cutting with a number of different mowers and mower conditioner systems followed by tedding or turning and for either wilting (60% moisture) or drying (35% moisture). He observed a relationship between yield in each category and the power requirement of the system. The total mechanical loss between cutting and baling, assumed to be the difference between the raked and the baled yields, was about 35% of mechanical loss for most of the mower conditioner systems with a power requirement of around 5 kW. These loss values would have been the mean of a long hay dry down and a shorter silage wilt and give no indication of loss per operation, however.

Many researchers have attempted to fit curves to represent mechanical losses. It is assumed that mechanical losses represent a combination of two distinct processes: true shatter loss takes the form of small particles of material breaking off whenever forage is disturbed, and pick-up loss takes the form of particles of unshattered material dropping between the pick-up tines bars and failing to be picked-up. There is ample evidence that shattering loss is related to the moisture concentration (and hence brittleness) of the material, and also to the severity of the treatment. There is no evidence, however, that pick-up losses are related to forage moisture concentration. Honig (1979) suggested that a factor that affects pick-up losses is the proportion of ground area over which the material being picked up is spread, and hence the number of inter-tine spaces through which the material can be lost. Shatter loss consists mainly of very small particles which can blow away or fall directly through the main bulk of material in the stubble. Pick-up losses can include longer particles, sometimes complete grass stems not clinging to the main mass of material, which manage to find paths between the tines of a conventional pick-up reel.

For shatter loss relationship, McGechan (1988) proposed a base level of percentage shatter loss in relation to moisture concentration based on experiments with a hay grass mixture.

$$L_s = \begin{cases} g[0.6+0.25x)], & m \geq 236-3D_c \\ g[0.6+0.25x+(1.42-0.02D_c)(236-3D_c-m)], & m < 236-3D_c \end{cases}$$

where g = 1 for tedding and spreading, 0.5 for turning, windrowing, rowing up and picking up, and x = 1 for conditioned grass, 0 for non-conditioned grass.

Concerning the effects of these losses on forage digestibility and protein concentrations, there is general agreement that respiration and leaching represent losses mainly from the WSC component of forage material. Since WSC is a part of the digestible fraction of the forage, a reduction in percentage digestibility will result from respiration and leaching losses. In experiments conducted by Murdoch and Bare (1963) with grass and Collins (1983) with lucerne, changes in nitrogenous components of forage were measured and found to be insignificant. This suggests that no change in CP content is expected when leaching losses occur.

During mechanized handling, particles of material containing both digestible and non-digestible fractions are lost, suggesting little or no change in the digestibility value arising from this type of loss. With alfalfa, however, as shatter losses tend to be mainly leaf material which is the most nutritious part of the plant, some reduction in digestibility will occur. McGechan (1988) in shatter loss susceptibility experiments with grass found that at silage moisture concentrations roughly equal quantities of leaf and stem material were lost. At hay moisture concentrations, more stem than leaf material was lost. This suggests that, if anything, a slight increase in digestibility arises with mechanical losses in grasses. It can be assumed from these conflicting results that no changes in digestibility or WSC and CP concentration occur when mechanical losses take place with grass.

Overview of Field Losses

The majority of studies have dealt with forage legumes, where losses from prewilting will be higher because of the high leaf/stem ratio. However, wilting in good weather conditions results in field losses below 3%. Rain will increase the magnitude of losses. No correlation has been reported between DM loss and weather for wilting periods less than one day (Nash, 1959).

Nutrient Losses during Storage

Hay Storage Losses

Losses during haymaking are clearly inevitable. They can, however, be minimized by a reduction of time in the swath which can be achieved by suitable mechanical treatment, by carrying out the last stages of drying on racks or tripods or in the barn, and by careful handling of the hay after it has been dried. Hay storage losses may be related to moisture concentration. Some additives (i.e., propionic acid) may be used to reduce storage losses when hay is harvested at higher moisture levels. Rees (1982) reviewed the literature about the mechanism and extent of losses in hay which has been put into storage at a high moisture concentration. For good hay stored at about 20% moisture concentration, he found storage losses of 2%, which included losses from both respiration and microorganism activity. Fungi are normally only active during storage when the humidity of the air in the interstitial spaces is above 70% and the temperature above 20 °C. Laboratory experiments have shown that the equilibrium moisture concentration of hay is about 18% at a relative humidity of 70%. In contrast to fungi, bacteria require a relative humidity of 95% to grow. Dry matter losses have varied from 0 to 25% under laboratory conditions and, in general, the higher the relative humidity, moisture concentration of the crop and the temperature, the greater are the losses. Rees (1981) maintained that the critical mass below which microbiological activity is not inhibited is governed by factors which include moisture concentration, density, spore infestation and temperature.

Nelson (1966) and Rotz and Davis (1983) reported with alfalfa hay increased losses with higher moisture concentration; the losses were higher than in grass crops and were typically around 6 to 8% at 20% moisture concentration. Higher losses may arise because of higher ambient temperatures occuring immediately after harvest and differences were attributed to type of crops.

Lechtenberg et al. (1980) reported DM losses (mean of 2 year data) for round baled hay of 23%, 15% and 8% DM for unweathered hay stored on ground, crushed rock and inside a barn. Nelson et al. (1983) reported storage losses of 23 to 26% for large round bale stored outside, 13% for those stored outside with covers, and 4% for bales stored in a barn. Feeding losses were 13 to 20% for large round bales uncovered outside, 1.4% for those covered outside, and 1% for those barn stored. Total losses were 44 to 51%, 15, and 5% for large round bales stored outside with no cover, outside covered, and inside, respectively.

Belyea et al. (1985) harvested alfalfa in large round bales or small square bales and determined storage and feeding losses for the different methods. Large round bales were stored 1) in a barn; 2) outside uncovered in single rows; 3) outside in two-high covered stacks; and 4) outside in three high covered stacks. The bales were fed to dairy heifers with small square bales for comparison. Dry matter storage losses were 2% for large bales stored inside, 6% for large bales stored outside cover, and 15% for large bales stored outside uncovered. Feeding losses of large bales were 12% for bales stored inside, 25% for bales stored outside uncovered, and 13 to 15% for bales stored outside covered. Total losses for large round bales were 40% for bales stored outside uncovered, 20% for bales stored outside covered and 15% for bales stored inside.

Parke et al. (1978) proposed the following relationship based on data from various sources assembled by Klinner (1976):

$$L_h=0.15m-0.25$$

where L_h = Losses of hay during storage, % DM and m= Moisture concentration.

Silage Storage Losses

Storage losses for silages are large, typically 20% or more, and the subject is very complex. Many factors which include degree of wilting, chop length, stage of maturity, and additives will affect the magnitude of these losses. The type of storage structure will also affect the magnitude of losses. The main mechanisms by which storage losses may arise involve the fermentation process, air infiltration and the production of effluent.

Anaerobic losses

The main biochemical pathways involved in the fermentation during ensiling, and the DM and energy losses associated with these pathways, have been described (McDonald, 1981; McDonald and Whittenbury, 1967; McDonald et al., 1968). Energy losses are generally lower than DM losses. McDonald and Whittenbury (1967) and McDonald et al. (1973) calculated DM losses associated with typical types of fermentations characterized according to the composition of the grass crop. Calculated losses totaled about 4% which they regarded as a typical maximum loss level for a good lactic acid fermentation of a grass crop, since some fermentation would be homolactic with no DM loss. These authors also suggested that the organic acid (citric and malic) content of a particular plant will influence the total fermentation loss. McDonald et al. (1964) calculated the proportion of substrate in the grass fermented by each reaction based on analysis of the fermentation products in the silage. This experiment used four silos and had DM losses below 2%. The proportion of fermentation by homolactic bacteria was relatively small.

Clostridial fermentation resulted in much higher losses on the order of 50 and 20%, respectively, for DM and energy (McDonald, 1981). Proteolytic activity occurring when the pH of the fermented silage is higher than 4.3 will result in deamination and decarboxylation of the amino acids liberated during enzymatic proteolysis (Macpherson, 1952; Carpintero et al., 1979). This degradation of the nitrogenous fraction may be detected as increasing ammonia-N concentration in the silage. The content of ammonia-N expressed as g/kg total nitrogen (TN) is a criteria of silage quality. Values below 80 g/kg TN are regarded as acceptable in silage (Breirem and Homb, 1970).

Lactate-assimilative and fermentative yeast growth may result in losses of DM because of the fermentation of WSC. The reaction due to enterobacteria are complex and not well understood. Their activities are considered undesirable, producing acetic acid and some deamination of nitrogen compounds, but they are less harmful than clostridia. They are most active under high pH conditions at the early stages of fermentation.

Fermentation losses are difficult to investigate. One main problem is to distinguish between losses caused by the fermentation and losses due to oxidation by air infiltration. McDonald et al. (1968) conducted research to separate fermentation and oxidation losses. In this experiment, a net was placed across the silo when it was about three-quarters filled. Total losses during the storage period were estimated by measuring the weight loss from the silo, and losses in the air damaged material above the net were also measured. Losses of material below the netting, calculated by subtraction, were very low and similar to the expected fermentation losses calculated by analysis of the fermentation products.

Jonsson et al. (1990) studied storage losses for bagged timothy/fescue herbage harvested at different DM levels. They reported losses in weights of big bales during storage of 4.8% for direct cut silage (25% DM), 3.1% and 4% for wilted silages at 35 and 50% DM respectively. Weddel and Mackie (1987) reported storage losses of 6% for bagged ryegrass/timothy herbage at 33% DM. Zimmer and Wilkins (1984) reported in-silo DM losses of 16.1% for unwilted silages made with additive and 8.5% for wilted silages made without an additive.

Aerobic storage losses

Losses due to air infiltration take place during filling the silo, during the storage period and during the feeding. At the initial stage of ensiling, the grass is alive and continues to respire, but the reduced oxygen concentration may constrain this process in parts of the silo. Respiration oxidizes the WSC component of the forage. It continues during the early stages of the fermentation until the oxygen has been used up. Any CO_2 produced by fermentation reactions tends to displace gases already present and accelerates the exhaustion of oxygen. After fermentation has taken place, grass is dead but some of the enzymes which control respiration in the live plant may still be present and some respirations under their control may continue if oxygen is available. A significant proportion of respiration during storage will be by the microorganisms, however. During the storage period, a layer of visibly spoiled silage is formed immediately below the polyethylene film and is known as "surface waste." There is also some evidence that invisible oxidation losses occur throughout the mass of silage during the storage period.

During the feeding period, aerobic microorganisms multiply and rapidly become the main mechanism by which oxidation of nutrient occurs. Generally less serious invisible oxidation losses take place but on occasions there can be serious local heating and molding which results in visibly spoiled material (Woolford, 1978).

Bastiman and Altman (1985) and Mayne and Gordon (1986b) measured surface waste in horizontal silos sealed by a plastic sheet. Under farm conditions, the former observed levels of surface waste which were higher in wilted silages compared with direct cut materials. Surface waste was lowest in silage made with a flail harvester, slightly higher with a precision chop or double chop harvester, and highest with a loader wagon, but in some cases the differences were small. Mayne and Gordon (1986b) found surface waste was under 1%, probably because of ideal experimental conditions. Total DM losses were 20.6%, 13.4% and 6% for unwilted flail, unwilted precision chopped and wilted precision chopped silages, respectively. Corresponding surface waste losses were 1.3%, 1% and 1.2%, and effluent losses were 2.9 and 2.5% for unwilted silages. No effluent loss was found with the wilted silages. Invisible losses comprising the highest proportion of loss were 16.4, 9.9 and 4.8%

for the unwilted flail, unwilted precision and wilted precision chopped, respectively. In another experiment, Gordon (1986) reported in-silo losses of 9.8, 7.6, 8.3, 13.2% OM with single-chop flail direct-cut, double-chop flail direct-cut, precision-chop unwilted and precision-chop wilted silage, respectively. Savoie et al. (1986b) reported DM losses of 14.8, 13.1 and 10.4% for grass preserved in stack silos as direct-cut, direct-cut formic acid treated and wilted silages respectively. Kjelgaard et al. (1981) reported storage losses of 6, 7, 4, and 10% for corn silage, wilted grass silage, baled hay (no rain) and round bale hay stored outside. Surface waste values measured in experimental silos during the series of experiments were reported by McDonald et al. (1968) and Henderson and McDonald (1975). Howe (1987) reported the effect of baler type (variable and fixed chamber) and DM levels (35%, 55% and 60%) at baling on storage losses of round bale silages. At 35% DM, storage losses were 2.6% and 5.9% for variable and fixed chamber balers, respectively. Values of storage losses at 55% DM were 4.6 and 3.9, and at 60% DM, storage losses for the two types of balers were 7.1 and 5.3, respectively. Shepherd et al. (1953) found storage losses of DM from wilted alfalfa silage in gas-tight silos to range from low values of 1.0 and 5.6% up to 11.9%. Silages in trench silos and stacks suffer from greater loss of DM than do materials in the upright type of silo (Shepherd et al., 1953). Moore (1958) reported losses for different methods of preservation of alfalfa. Storage losses were 4, 3.6, 6.4, 1.8, 11, and 4.1% for field-cured hay (rain damaged) field-cured hay (no rain), barn dried hay (no heat), barn-dried hay (heated), wilted silage and dehydrated hay, respectively. Gordon et al. (1959) reported DM losses for first-cutting orchardgrass preserved as wilted silage stored in a tower silo, direct-cut sodium metabisulphite-treated silage stored in a tower silo and direct-cut sodium metabisulphite-treated silage stored in bunker silo. The total losses were 13.7, 22.1 and 14.8 for wilted and direct-cut silage stored in tower silos and bunker silo, respectively.

Some studies have been reported in which "invisible loss" has been measured by comparing the weights of material in and out of silos, then substracting the weights of visibly spoiled material and effluent. Zimmer and Wilkins (1984) have collated values of in-silo losses from a series of coordinated silage wilting trials carried out in several European countries, and found a similar decrease in loss with an increase in DM concentration. They also observed lower loss levels with formic acid. There were variations between countries in experimental techniques and in the categories of loss included in these overall loss figures, however. Ulvesli et al. (1965) and Zimmer (1967) comparing long to chopped material, observed a reduction in storage losses from 13.5% to 4.8% with direct cut silage and a reduction in overall losses from 27.1 to 18.0%.

Overview of Storage Losses

Studies on storage losses have been implemented mainly in laboratory silos where the magnitude of these losses may be low because of controlled experimental conditions. Redman (1985) reported that storage losses may approach 15% with round bale silage that have DM concentrations of 25% or less. Above 35% DM content losses in storage should not exceed 10%. Howe (1987) reported losses at baling in the range of 2.6 to 6% at 35% DM and 4 to 5% at 55% DM and 5 to 7.1% at 60% DM. Storage DM losses are about 15% for round bale hay stored outside and uncovered (Beleya et al., 1985; Nelson et al., 1983; Lechtenberg et al. 1980).

There is a lack of data on feeding losses of silages. Feeding DM losses ranged from 13 to 20% for silages (Lechtenberg et al., 1980) and were about 25% for round bale hay stored outside uncovered (Belyea et al., 1985). Feeding losses of round bale silages may be higher than that of hay and based on field experience a value of 25% will be considered.

Effect of Conservation Method on Voluntary Feed Consumption

Profitable animal production almost always requires an efficient conversion of feed into animal products. Efficient feed conversion, however, will be achieved only if the animal is able to obtain from the feed a substantial margin of nutrients over maintenance requirements. In many production systems, nutrient intake is set by the voluntary intake of the animal. Short term increases in feed intake almost always lead to improved feed conversion efficiency; with growing ruminant animals the long-term effects of increased feed intake are marked because the number of feeding days required to reach a given liveweight is reduced. Nutrient changes as related to conservation processes which involve reduction of WSC, breakdown of the protein fraction during field-curing (hay or wilted forages) and production of organic acids from the fermentation of WSC (silage fermentation), will determine the intake potential of a conserved forage. Demarquilly et al. (1981) found that the voluntary intake of hay was related linearly to that of the fresh herbage.

Many reports in the literature show that the intake of silage is less than that of fresh forage or hay from the same crop. Waldo et al. (1966) found that when offered ad libitum to heifers, voluntary intake of silage was 28% lower than that of hay. Demarquilly (1973) reported that the intake of 87 silages by sheep was on average 33% lower than that of the fresh crops from which they were made. The relative depression, however, in silage intake ranged from 1 to 64%. Demarquilly (1973) noted that this high variation may be explained partly by problems associated with the determination of DM and partly with the unwilted silages as emphasized by Gill (1989). The DM concentration of unwilted silage is frequently underestimated by oven drying since the alcohol and volatile fatty acids content of unwilted silage are usually ignored. The magnitude of the difference observed with some silages, however, indicates that analytical problems are not the sole factor contributing to the lower silage intake recorded.

Several workers have found increases in intake of forages with increasing DM concentration. Jackson and Forbes (1970) reported voluntary intake by cattle of timothy/meadow fescue silages differing in DM concentration. The DM concentration of experimental silages were 19, 27.3, 32.3 and 43.2%. There was a reduction in the concentration of lactic and acetic acids as DM concentration was increased by wilting. Intake increased so that the intake of silage wilted to 32% DM was 21% greater than that of the unwilted silage (19% DM). The correlation between the concentration of DM and fermentation acids precludes the elucidation of the role of DM concentration per se, however. Wilkins et al. (1971) and Demarquilly (1973) found that correlations between intake and DM concentration were not as high as those between intake and the concentration of volatile acids (such as acetic acid) or the proportion of total N as ammonia. This finding would indicate that the improvement in intake with increasing DM concentration was associated with a reduction in the concentration of acetic acid in the wilted silages rather than a reduction in lactic acid or total acid concentration. Jackson and Forbes (1970) found that intake was linearly related to the concentration of acetic acid in the silages and that the correlation between intake and the concentration of acetic acid was higher than that between intake and the concentration of lactic acid. In a later experiment (Forbes and Jackson, 1971) intake of a wilted silage with 35% DM was found to be 52% greater than that of the unwilted silage with 19% DM, despite the fact that there was little difference between the two silages in their concentrations of lactic acid. The unwilted silage, however, contained 6.0% of DM as acetic acid compared to 1.7% of DM as acetic acid in wilted silage. Working with unwilted silages, McLeod et al. (1970) concluded that intake was restricted by their free acid concentrations. Fermentation characteristics were shown to be the most important silage factors limiting intake, and butyric acid was shown to be more important than other volatile fatty acids or ammonia nitrogen. Neutral detergent fiber was found to be better related to intake than were other fiber or digestibility measures.

Dulphy and Rouel (1988) studied the effect of wilting on changes in the voluntary feed intake in cattle as compared to sheep. Twelve hays were harvested under very good weather conditions and four during rain. The fresh control forages were harvested every day and offered to sheep and 15-month old Holstein heifers. The fresh forage sample was cut during the same week that the corresponding hay was prepared. The mean amounts ingested of fresh forage were 67 g DM/kg $W^{0.75}$ for sheep and 88.8 g DM/kg $W^{0.75}$ for heifers. For the 12 hays prepared under good weather conditions, the voluntary intake relative to that of fresh forage was reduced by 19% in sheep and by 5% in heifers. The reductions were 30% and 8%, respectively, for the other four hays. In this experiment the intake of hay tended to be higher than that of the fresh herbage. An explanation was that the high water concentration of the fresh forage may have limited intake indirectly by a fill effect (Verite and Journet, 1970). An alternative explanation was the adaptation of heifers to the experimental forage diets during winter. They reported a difference in voluntary intake of 10% between the beginning and the end of winter.

Campling (1966) reported three comparisons of hay and unwilted silage prepared from the same crop, and showed that on average, 28% more DM was eaten as hay than as silage. Silage residues tended to remain in the digestive tract longer than hay residues, although the digestibilities of silage and hay were similar. The cows stopped eating silage well before the amounts of digesta DM in the reticulo-rumen were equal to those found when cows were offered hay ad libitum. This suggests that the voluntary intake of silage was not limited by the capacity of the reticulo-rumen at the end of the meal. Although the large amount of water in silage may have limited intake, the addition of 45.45 kg of water to the rumen of cows eating hay had no adverse effect.

Donaldson and Edwards (1976) compared the voluntary feed intake of fresh cut grass with silages made from freshly cut grass, wilted grass and formic acid treated wilted grass. The intake of fresh forage was 11.2 g/kg liveweight. Intakes of DM were depressed by fermentation and were 12.3, 9.7 and 8.5 g/kg liveweight for the acid treated, prewilted and directly ensiled, respectively. Fermentation improved the metabolizable energy (ME) concentrations which were 11.6, 12.0, 11.4 and 13.6 MJ/kg DM for the grass, the acid treated, wilted and directly ensiled materials. Fermentation reduced the intake of ME and the production potential of the material. It was concluded that the major factor affecting the feeding value of silage was the DM intake.

Dulphy and Michalet (1977) observed intakes at 97% of fresh material for seven direct-cut, formic-treated silages fed to heifers. Intakes relative to fresh material were higher for dehydrated forages cut with a blade or sickle. In contrast, Demarquilly and Jarrige (1970b) reported forage preserved as either hay or silage had lower DM intake than the fresh forage in an extensive summary of intake data with sheep. Granier and Razafindratsita (1971) fed prewilted fresh and unwilted green chop forages of Tripsacum laxum (guatemala-grass) to milking cows. Wilting increased the intake of DM by 24%. These observations suggest that the intake of silages may be primarily limited by undesirable fermentation products. Many researchers have reported significant correlations with individual end-products of fermentation

(Wilkins et al., 1971; Demarquilly, 1973), but as with other aspects of intake control, no single end-product is primarily responsible, since negative responses to more than one constituent of silage effluent have been obtained (Buchanan-Smith and Phillip, 1986). Thomas et al. (1980) reported that addition of lactate to silage decreased intake of silage alone, but had no effect when the silage was supplemented with fish meal. Intake responses to the addition of acids to silages have been widely variable, and no satisfactory theory exists to explain the interaction between fishmeal and lactic acid. Gill and England (1985) reported that fish meal alone tends to increase the intake of silage when expressed in terms of kg DM/day, but not when intake is expressed in terms of g DM/kg LW. They suggested that the increase appeared to be mediated in the rumen, since the digestibility of organic matter was also increased and since the effect of the relatively undegradable protein can also be achieved with more degradable proteins such groundnut and soybean meals when used as supplements with poor quality silages. Overall, the effect of protein supplementation on silage intake decreases as the N content of the silage increases. Characteristics of the plant as harvested and the efficiency of the ensiling process will influence the voluntary intake of the end-product.

The relation between intake and the weight of NDF concentrations in the rumen has been investigated (Moseley and Jones, 1984; Ulyatt et al., 1984; Aitchison et al., 1986). These studies showed that the pool sizes of DM and NDF increased with increasing levels of intake, but the percentage increases were less than the percentage increase in intake. It seems that the animal is compensating to some extent for the increase in intake by increasing the rate of passage of material out of the rumen. For intake to be restricted, a maximum degree of fill must be reached. It was originally assumed that this maximum degree of fill was fixed relative to animal size and physiological state. It is known that with a high fiber feed imbalanced in some other respect (i.e., protein, minerals, branched chain fatty acids), the degree of fill attainable will be less than with a balanced feed. Egan (1970) showed that protein infused into the duodenum could increase the degree of gut fill in sheep offered low-N hay, supporting this theory. Flores et al. (1986a; 1986b) suggest that the relatively poor nutritive value of high moisture alfalfa silage is likely to be related to an insufficiency of specific amino acids for tissue metabolism. Studies with sheep fed silages have shown increases in voluntary intake (Gill and Ulyatt 1977; Barry 1976) and improvements in nitrogen retention (Barry et al., 1978) in response to postruminal supplementation of methionine however. These results have not been consistent (Kelly and Thomas, 1975; Barry et al., 1978). Merchen and Satter (1983) reported that ensiling had no effect on the proportion of methionine and other amino acids in duodenal digesta. It was the absolute supply of amino acids that was influenced by ensiling.

Peters and Harper (1981) linked food intake regulation to the concentration of branched chain amino acids (BCAA) in plasma. Research with sheep (Mercer and Miller, 1982) has shown a linear relationship between plasma levels of BCAA plus threonine and lysine, and their concentration in duodenal digesta. Thomas et al. (1980) reported a high correlation between intake of BCAA and other amino acids and their passage to the duodenum in sheep fed silage. An increase in voluntary intake due to supplementation of low-N hay may be due both to increased rate of fiber digestion which decreases gut fill and to increased protein flow to the duodenum which has been shown to increase the degree of gut fill.

There is evidence that intake of silage increases with increasing digestibility of roughage (McCullough and Burton, 1962). Some equations for cattle do include digestibility as a significant variable (McCullough, 1966). In individual experiments digestibility has been found to markedly affect intake where the quality of fermentation is controlled (Thomas et al., 1984a; Thomas et al., 1984b). McCullough (1966) found a correlation of 0.85 between silage DM digestibility and DM intake. In contrast to the control of intake of hay, early attempts to derive relationships between digestibility and silage intake were unsuccessful (Harris and Raymond, 1963; Wilkins et al., 1971). Many factors are implicated in the control of hay and silage intake. There is a lack of comprehensive studies on the interrelations among these factors, however. Attempts to relate patterns of intake of conserved forages to changes in rumen fill, rumen motility and rumen fermentation characteristics may provide a better understanding of these interactions. Campling (1966) observed that rate of intake of silages by cows was less than that of hay made from comparable forage. Demarquilly and Dulphy (1977) observed that eating rates of different silages were correlated to their total intakes in heifers and sheep and that silages were eaten in a greater number of meals than was the case for the corresponding fresh forage. Ruminants fed silage have a low rumination activity and a long 'latency period' after feeding (Deswysen et al. 1978) and this may impose special limitations on the physical breakdown of silages in the rumen. Dulphy et al. (1980) concluded from these data that impaired palatability was an explanation for the intake effect. Clancy et al. (1977) showed that intraruminal infusions of silage juice reduced rumen motility and rate of eating, but the results have not been reproduced with consistency (Phillip et al., 1981a; Phillip et al., 1981b; Smith and Clapperton, 1981). To separate ingestive factors involving palatability from post-ingestive factors responsible for forage intake being depressed by ensiling, Buchanan-Smith (1990) used sham-fed animals to evaluate silages. The silages tested were high moisture silages reconstituted with either water, solutions containing constituents commonly found in silage, or extracts of low DM silage. Solutions of silage constituents were adjusted before reconstitution to a pH typical of silage. The addition of lactic acid and acetic acid to concentrations of 53.2 and 35.4 g/kg, respectively, increased intake with a linear response due to total concentration of these acids. Acetic acid added at 88.0 g/kg depressed intake with a linear response; acetic acid added at 10 g/kg depressed 30-minute intake by 13.5 g. The addition of acetic and butyric acids together and at different concentrations did not affect intake. Similar results were found with ammonia added at 3.8 g/kg as ammonia nitrogen (N). A mixture of free amino acids added to a level of 9.2 g amino acid N per kg was without effect, but at a level of 13.8 g/kg, intake was depressed 75 percent. A mixture of two amines and gamma amino butyric acid added at concentration up to 4.6 g N/kg caused a quadratic response in which intermediate levels enhanced intake, but the higher concentration had no effect. An extract from good-quality silage had no effect on intake and that from a poor-quality silage depressed intake in a linear manner. It is concluded that elevation of acetic acid in silage without increases in amounts of other constituents decreased intake of silage through an effect on palatability.

Gill and England (1985) compared hay and silage made from the same sward cut on the same day. The silages were well preserved with a pH of 3.8 and a lactic acid concentration of 5.2% (DM basis). The silage was preserved unwilted and had a DM concentration of 21%, while the hay had a DM concentration of 82.2%. The hay was chopped to a similar length to the silage before being offered to the cattle. Ad libitum intake of the silage (24.4 g DM/kg LW) was 12% less than that of the hay, but for the purposes of the more detailed study, the intake of hay and silage were restricted to the same level (20 g/kg LW) and were offered to young cattle (average initial liveweight of 127 kg) once daily. The eating patterns observed were similar to many others recorded for silage in that the calves ate many small meals compared to one large one for hay. The daily allocation of hay was consumed within 2 h, while the cattle took 12 h to eat the silage. The weight of DM in the rumen was initially (up to 12 h post-feeding) less for cattle offered silage than for those offered hay, and this was correlated with a more rapid fall in pH for the silage (Gill, 1989). From 12 to 14 h post-feeding, the weights of digesta were very similar. These data suggest that some factors released during the initial rapid solubilization of the silage signaled the end of the first meal, but latter in the day, gut distension may have been the primary limitation of intake. This study showed maximum contractile activity of the dorsal rumen sac occurred around 13 h after feeding, suggesting that in animals offered grass hay once daily, a mechanism exists wereby the fiber is retained in the rumen to allow maximal digestion and is only removed from the rumen in time to allow ingestion of the next feed.

Effect of Conservation Method on the Digestibility of Forages

The digestibility of the preserved forage is largely governed by the digestibility of the parent material (Demarquilly and Jarrige, 1970a) which in turn is affected by the species of plant and its stage of maturity at cutting (Harris and Raymond, 1963; Castle, 1975; Kormos and Chesnut 1967; McCarrick, 1965). Ensiling per se did not significantly alter digestibility of herbage, provided correction for volatiles was made (Harris and Raymond, 1963). The data of McDonald and Edwards (1976) and Donaldson and Edwards (1976) support this conclusion. Other research data have shown the effect of ensiling on digestibility to be highly variable (Dijkstra, 1957; Watson and Nash, 1969; Demarquilly and Jarrige, 1970b) with a tendency for digestibility to be reduced by ensiling.

The effect of wilting as an additional treatment to direct ensiling on digestibility of silage was in most cases a reduction in digestibility. Marsh (1979), in an excellent review on the effect of wilting on the nutritive value of forages from forty different sources, reported an increased digestibility from wilting in only ten experiments. The mean digestibility coefficients for unwilted and wilted silages were 0.700 and 0.685, respectively. The difference of

0.015 units contrasts with the apparent 0.004 unit-increase observed by Demarquilly (1973). He noted that results of Demarquilly (1973) were not from paired comparisons. In experiments where more than one level of wilting was compared, no further significant decline in digestibility was observed beyond the wilted silage with the lowest DM concentration (Gordon et al., 1965; McDonald et al., 1968; Jackson and Forbes, 1970; Forbes and Jackson, 1971).

Many researchers, however, have concluded that no differences in digestibility of nutrients exist between direct cut and wilted silages (Murdoch et al. 1958; Gordon et al., 1959; Ely et al., 1949). Butterworth and Diaz (1970) observed no differences among silage, hay or fresh material made from tropical forages in their ability to predict the nutritive value of plant. Harrison (1942) observed lower digestibilities when tropical forages were wilted; however, Yoelao et al. (1970) observed an increase in digestibility of all nutrients when the forage were wilted. Grant et al. (1974) reported, in an experiment using cattle and buffaloes, that wilting markedly increased intake and digestibility of napier grass and significantly lowered metabolic losses. They suggested that some chemical or enzymatic change within the plant during the wilting period caused an increase in digestibility of the cell wall.

The effect of wilting on apparent N digestibility has received less attention; the results of twelve comparisons from nine sources (Nash, 1959; Gordon et al., 1961; Hidiroglou et al., 1965; Hinks et al., 1980) showed a 0.029 unit decline in N digestibility due to wilting (0.658 vs 0.629). Thomson and Beever (1981), using the quantitative digestion data of Beever et al. (1971a) for fresh grass and wilted and unwilted silage fed to mature sheep, expressed the results for N flow and absorption in relation to the N content of the original crop prior to conservation. They concluded that amino acid N flow to the duodenum of sheep fed fresh grass was equivalent to 63% of the N in the original crop, and amino acid N absorption amounted to 41%. The corresponding values for wilted silage (47 and 31% respectively) were much lower, while the values for unwilted silage were intermediate (54 and 41% respectively). Urea nitrogen reached more than 50% of the original N of the crop on all diets because they were fed at restricted levels of intake to mature sheep. The two silage diets showed values of urea N in excess of 60% and, consequently, N retention was highest on the fresh diets, with the unwilted silage appearing to be superior to the wilted crop.

Kraem et al. (1990) studied the influence of the method of forage preservation on fiber and protein digestion in cattle given lucerne, birdsfoot trefoil and sainfoin. Animals were fed all-forage diets which included lucerne hay and silage, birdsfoot trefoil hay and silage and sainfoin hay and silage. Organic matter, hemicellulose and cellulose digestibilities were similar. Crude protein digestibilities were lower for sainfoin than for lucerne or birdsfoot trefoil, however. Presence of tannins in sainfoin may have been responsible for low protein degradation in the rumen and reduced N digestion in the small intestine. Forage preserved as hay or silage had similar fiber and OM digestibilities, while CP digestibilities were higher for silages than for hays. Rogers et al. (1979) reported higher N digestibility for direct cut silages than 50% wilted grass silage (60.5 vs 55.4%). The wilted silages had a higher N digestibility than formalin-treated silages (55.4% vs 44.8%). Durand et al. (1968) compared fresh lucerne with the same crop conserved as unwilted (23% DM) or as wilted (37%) silage. Differences in apparent N digestibility between the three forages were small.

Effect of Conservation Method on Nutrient Utilization

The gross energy (GE) concentration of forages is about 18.4 MJ/kg DM, except for silages, for which it is about 20 MJ/kg DM. Feed rich in fatty acids or in proteins have GE values > 18.4 MJ and those with a high ash content have lower values. Graham (1967) reported values of 19.2, 17.65 and 18.78 MJ/kg DM, respectively, for fresh Desmodium, Sorghum almum and Digitaria decumbens. The proportion digested, hence digestible energy (DE) concentration, is reduced by hay making, but not by artificial drying or ensiling. Wilting may or may not reduce DE, depending on its effect on digestibility, however. Losses of energy as methane during rumen fermentation of conserved forages appear to have little variation and range from 7 to 9% (Greenhalgh and Wainman, 1980). Graham (1967) reported methane and urinary losses of energy for fresh warm-season grasses of 11 to 13% and 6 to 12%, respectively. Most tabulated values of ME concentration are derived from data for the digestibility of OM or energy. The conversion factors used are 15 MJ ME/kg digestible OM or 0.81 MJ ME/kg digestible energy (DE) (MAFF, 1975). For converting forage DE to ME, NRC (1984) used a factor of 0.82. Calorimetric studies to determine losses of energy from silages as heat and methane (CH4) are few (Wilkins, 1974; Smith et al., 1977) and there is a lack of data comparing wilted and unwilted silages made from the same material. McDonald and Edwards (1976) concluded that the conservation method did not greatly affect methane losses, which accounted for 7 to 9% of ingested gross energy (GE). Silages of 29% and 50% DM have been found to loose less GE as methane (7.5 and 7.9%, respectively) than hays made from the same material (8.3 and 8.1%) (Ekern and Sundstol, 1974). Furthermore, such losses, as percentage of GE, tend to decrease with increased intake (Smith et al., 1977). Jackson and Anderson (1968) reported that urinary energy (UE) losses as a proportion of GE also decreased with increasing intake and that, at equal feeding levels, UE losses were lower from wilted than from unwilted silage; these findings have also been confirmed by the results of McDonald and Edwards (1976). Many authors have reported higher ME and digestible organic matter (DOM) ratios for wilted silages than unwilted silages (Forbes and Jackson, 1971; Donaldson and Edwards, 1976; Hinks et al., 1976).

Wilkins (1974) and McDonald and Edwards (1976) in their reviews have pointed out that N is retained with less efficiency from silage than from fresh or frozen herbage. There is, however, evidence showing that efficiency of retention of digested true protein is higher from wilted than from unwilted silages (Fatianoff et al., 1966; Joyce and Brunswick, 1975). These improvements in efficiency of retention of DE and N would therefore tend to offset the lower digestibility of these nutrients in wilted silage. These differences between silages in digestibility and efficiency of utilization are small and can therefore be readily offset by differences in intake, however.

Effect of Conservation Method on Animal Performance

Both animal and silage factors can influence the potential for high rates of liveweight gains (McIlmoyle and Steen, 1979). Flynn (1973) observed that the efficiency of utilization of the extra intake resulting from wilting was low in beef cattle. Marsh (1979) found no significant effect on milk yield, despite higher intake of silage made from wilted material. Investigations by Gordon (1981) showed that wilting caused a significant reduction in milk yield indicating that it reduced the efficiency of utilization of silages by the animal.

McCarrick (1966) has shown that gut fill in ruminants may be greater with wilted than with unwilted silages, whereas Flynn (1973) found that wilting increased liveweight gain but did not increase carcass gain. Bartholomew et al. (1980) compared the effect of unwilted and wilted silages and hay supplemented with different amounts of concentrates on liveweight gain of calves. Calves fed wilted silages consumed 49%, 9% and 20% more forage DM, respectively, than those fed unwilted silage in the three experiments, but this extra intake was generally not reflected in an increased rate of gain. Hay which was of lower digestibility than silage gave lower liveweight gain. Steen (1985) compared three methods of harvesting grass silage for beef cattle. Harvesting silage with a precision chop rather a flail forage harvester produced a small increase in intake and liveweight gain, but did not affect carcass gain per hectare. Wilting for 20 to 24 h in ideal weather did not affect beef output per hectare, but 30 to 80 h wilting reduced beef output per hectare by 11 per cent. Cottyn et al. (1985) compared three silages prepared from perennial ryegrass: unwilted without additives, unwilted treated with 3.5 litres commercial (85%) formic acid, and prewilted without additives with DM concentrations of 19%, 21% and 33% respectively. The three silages were offered ad libitum in a 348-d feeding experiment to three groups of eight Belgian white-blue bulls with an initial liveweight of 277 kg. The concentrate (4.7% digestible CP) supplementation was 7.5 g/kg LW. Formic acid treatment improved the digestibility of all nutrients but CP, whereas wilting slightly decreased digestibility of all nutrients except DM and ether extract. The daily LW gain averaged 912 g and was not different on the three different treatments. Dry matter intake per kg $LW^{0.75}$ was higher with the unwilted treated silage (69.3 g) and with the wilted silage (71.6 g) than with the unwilted non-treated silage (65.8 g). This difference in DM intake, however, was not reflected in either daily LW or carcass gain. The DM of unwilted, non-treated silage was more efficiently utilized than DM of unwilted, treated or wilted silage. Charmley and Thomas (1987) studied the effect of wilting ryegrass prior to ensiling on conservation losses, silage fermentation and growth of beef cattle. At the ad libitum level of feeding, steers given wilted silage gained more liveweight and empty body weight than those given unwilted silage. Steers given wilted silage contained less fat and energy in the body at slaughter than those given unwilted silage, however. Thus, wilting did not influence the efficiency of utilization of DE for energy retention nor the efficiency of utilization of dietary protein for gain. Since efficiencies by the animal were similar and the increased field loss on wilting was partly compensated for by a reduced silo loss, it was concluded that the proportion of energy and protein in the standing crop retained by the steers was unaffected by wilting. The same authors showed that when steers were given similar amounts of DE and the unwilted silage was well preserved, neither use of formic acid nor wilting influenced gains in protein and energy. Further, the duration of wilting, in the absence of any differences in DM concentration, had no effect on animal performance (Charmley and Thomas, 1989). The response of growing cattle to wilted silages has been low when concentrates are fed (Marsh, 1979; Mikko et al., 1982).

A comparison of unwilted and wilted silages in a series of experiments conducted with temperate grasses throughout Europe has been described by Zimmer and Wilkins (1984). The survey concluded that DM intake was increased by about 4% in dairy cows and 9% in fattening cattle. These higher intakes were not, however, translated into improved production partly because wilting reduced digestibility by 2 to 3% units. With dairy cows, milk yield was decreased by 2 to 3% and weight gain by 7% when feeding wilted compared with unwilted silages. Liveweight gain of growing cattle was reduced by just over 4% as a result of wilting. It was calculated that production per hectare from wilted silage would be 91 to 95% of that from unwilted silage. It was noted that the performance from wilted silages was markedly lower if field wilting was prolonged or the crop was heavily contaminated with soil.

CHAPTER III
EFFECT OF HARVESTING SYSTEMS ON STORAGE LOSSES AND NUTRIENT UTILIZATION OF BERMUDAGRASS BY GROWING CATTLE AND SHEEP

Introduction

The harvesting system of forage plants affects the amount of forage consumed and the efficiency of conversion of nutrients into animal products. Forage harvesting alternatives include grazing, drying for hay or collecting and storing high moisture forage. Hay is often made into small rectangular or big round bales. High moisture forage harvesting and storage alternatives include: chopping the forage and storing it in vertical silos, horizontal silos or long plastic tubes; and baling unchopped forage in round bales and storing in bags or tubes, or individually wrapping them with "stretch wrap" polyethylene. At the farm level, nutrient recovery, forage quality and costs are important factors determining the method of harvesting, storing and feeding.

Harvesting losses increase as the length of time the forage crop remains in the field after cutting increases. The storage method also determines the length of field-curing. To prevent spoilage and risk of heating and fire in conventional rectangular bales, the moisture concentration should be less than 22%, while 18% moisture concentration is suggested for large round bales. Losses of DM for field-cured hay can be high, ranging from 26 to 54% depending on rain damage and leaf loss; barn-dried hay baled at a moisture content of 25 to 35% has lower levels of field and harvesting losses than field cured hay (Hewitt, 1986).

With forage plants stored at high moisture concentration (70% or more), field and harvesting losses are minimized, but storage, fermentation and seepage losses may be increased. Prewilting the grass to a moisture concentration lower than 70% at harvest may increase field losses depending on weather (rain), but fermentation and seepage losses during storage are lower. Forages with moisture concentrations below 40%, however, are sensitive to air penetration, molding and heating which may damage protein (Woolford, 1984).

Voluntary intake of forage may be reduced when DM concentration of the forage is low. Thomas et al. (1969) showed that voluntary intake of silage DM for all classes of cattle increased linearly when DM concentration increased from 18 to 54%. Demarquilly and Dulphy (1977) reported that intake of silage from unwilted forages was lower than that of corresponding fresh, frozen, dried, or wilted grass. In a review, Waldo (1977) reported that the average intake of silage with 30% DM or less was 83% of the intake of similar forage stored as barn dried hay. Verite and Journet (1970) compared voluntary intake of fresh and partly dried forages and suggested that a reduction of intake only occurs below a minimum DM concentration. Jackson and Forbes (1970) and Forbes and Jackson (1971) reported that the optimum DM concentration for maximum voluntary intake of silage was 30 to 35% for legumes (Lolium perenne) and grass-legume mixtures. In contrast, Demarquilly and Dulphy (1977) concluded that a well-preserved silage containing 23 to 25% DM was consumed as well as the corresponding hay or fresh forages.

Although there seems to be general agreement on increasing intake of forage with increasing DM concentration, advantages of a higher forage DM concentration on animal production have not been consistent. Some studies suggested that wilting may result in higher gut fill (McCarrick, 1966). Others suggested that the ME of wilted silages was used less efficiently than well preserved unwilted silages (Flynn, 1988). Flynn (1988) suggested that wilting increases animal production only with poorly-preserved silages. Bates et al. (1989a) reported an increase in bermudagrass silage intake on the order of 25% as a result of wilting. Most studies with temperate forages showed that wilting resulted in a 5 to 10% increase in intake (Marsh, 1979), but this improvement in intake may not offset the decrease in digestibility and efficiency of nutrient utilization often attributed to wilting (see Literature Review).

The digestibility of conserved forages depends on changes in WSC (respiration and fermentation), protein quality (heat damage protein and proteolysis) and leaf/stem ratio during harvesting and storing. Harris and Raymond (1963) concluded that ensiling per se did not significantly alter digestibility of herbage, provided correction for volatiles was made. Atwal (1983) reported no differences in chemical composition and digestibilities of nutrients for first-cut alfalfa preserved as round bale hay, formic acid treated round bale silage and wilted round bale silage. Gordon et al. (1961) and Petit et al. (1985) reported similar digestibilities for alfalfa, timothy and a mixture of red clover-timothy-Kentucky bluegrass conserved as wilted silages and hay. The crude fiber digestibility of the silage was five percentage units higher and the protein digestibility of the silage was three percentage units lower than that of hays. Roffler et al. (1967) found better digestibilities for silages than comparable hay. Thomson and Beever, (1981) reported higher fiber digestibility and lower N digestibility of perennial ryegrass silages compared to fresh grass or hay.

Nitrogen retention in ruminants fed silage diets has been lower than in those fed fresh herbage or hay (Waldo et al., 1966). Conrad et al. (1961) found that N utilization was similar for hay, silage and fresh herbage when N concentration was below 2.4% DM. Above this concentration, retention of N from silage was lower than that of fresh herbage and hay. Fattianoff et al. (1966) concluded that ensiling reduced N retention in sheep only when the silage was poorly preserved. Fattianoff et al. (1966) showed better N retention for wilted silages than for unwilted silages. Waldo (1979) showed that formic acid treated silage reduced rumen ammonia concentrations and improved N retention.

Ruminant production under most practical conditions is limited by intake of digestible nutrients in the diets. Feeding stored forages may reduce supplemental feed costs when the forage can be harvested at the optimal quality. There is a lack of research on the efficiency of feeding stored tropical grasses.

The general objective of this study was to evaluate harvesting, storing and feeding alternatives that could optimize the utilization of tropical grasses as winter feed for beef cattle. Specific objectives were:

1) to assess nutrient recovery of bermudagrass harvested and stored as round bale hay, unwilted round bale silage and wilted round bale silage, and

2) to compare the effects of differing systems of harvesting, storing and feeding on intake of digestible nutrients and animal performance.

Materials and Methods

Forage Management and Storage

The experiments took place during 1988-89 (experiment 1) and 1989-90 (experiment 2) at the University of Florida, Pines Acres Research Farm, Citra, FL. A sward of mixed tropical grasses was grown on Gainesville loamy fine sand. The sward was dominated by 'Coastal' bermudagrass (Cynodon dactylon) (approximately 85% of the covered area), the remaining being bahiagrass (Paspalum notatum) and other species. The fields were grazed by cows until early June each year. During the period of forage harvesting the sward received each year 448 kg/ha of fertilizer (18-8-8) proportionately applied after each cutting. The sward was cut at 5 to 6 weeks and 6 to 7 weeks regrowth during 1988 and 1989, respectively. The grass was cut and mechanically conditioned using a New Holland model 489 haybine and round baled using a New Holland model 848 baler. For the direct cut silage, the forage was cut, baled immediately, and wrapped in a "stretch wrap" polyethylene film (Farm Bale Seal stretch^{Tm} wrap film provided by Farm Bag Supply, Inc., Glenford, Ohio) for storage. Wilted forage was dried to an estimated 35 to 40% DM which required 1 to 2 h or 45 to 50% DM which required 2 to 4 h under good drying conditions, then baled and wrapped with polyethylene. The grass harvested as hay was field-cured for 2 to 3 days and baled. All bales were weighed at harvest on an electronic scale. The plastic wrapped bales were stored in the field under trees to reduce sunlight exposure of the plastic. The round bales of hay were stored in a barn. After 2 to 7 months of storage the bales were core sampled and weighed prior to feeding.

Storage Losses

The experiments were conducted as a complete randomized design with bales as experimental units. Twelve bales from each treatment each year were used to calculate DM recovery according to the formula:

$$\%DM\ recovery = \frac{Feeding\ forage\ DM * Feeding\ bale\ weight}{Harvest\ forage\ DM * Harvest\ bale\ weight} X\ 100$$

The experiment was analyzed by analysis of variance (Snedecor and Cochran, 1989) using the General Linear Models procedure of the Statistical Analysis Systems (SAS 1986).

$$Y_{ij} = \mu + T_i + \epsilon_{ij}$$

where

Y_{ij} = bale DM recovery.

T_i = fixed effect of treatment.

ϵ_{ij} = random residual error.

Animal Trials

Intake

Sixty-eight crossbred beef heifers and twelve crossbred steers averaging 250 kg in experiment 1 and eighty crossbred heifers averaging 235 kg in experiment 2 were assigned with respect to sex, breed and weight to eight pens (two pens/treatment). In experiment 1, the twelve steers were assigned to the treatments in order to have 3 steers per treatment.

The experimental treatments included round bale hay (hay), unwilted round bale silage (none), 1 to 2 hour wilted round bale silage (1 to 2h-wilted) and 2 to 4 hour wilted round bale silage (2 to 4h-wilted). In experiment 1, the feeding trial consisted of 87-day period from December 14 to March 11. At day-0, the full weight, height and body condition score of heifers and steers were recorded. The heifers and steers were left overnight without feed and at day-1 the shrunk weight was recorded. At day-87 and day-88, the full weight, height, body condition score and shrunk weight were recorded. In experiment 2, the feeding trial started on November 27 and ended on March 5. Full weight of heifers, height and condition score were recorded on day-0 and day-98 and shrunk weight was recorded on day-1 and day-99. The experimental groups were maintained on average quality hay ten days prior to starting the experiment. Full weight of the cattle was also recorded after maintaining the animals on average quality hay for eighteen or nineteen days after the trials were ended.

Each round bale was sampled, weighed and placed in a round bale feeder according to the respective treatment groups. Forage not consumed was collected by raking, weighed and sampled. Intake of forage (none, 1 to 2h-wilted, 2 to 4h-wilted silages and hay) was calculated for each pen as the weight of the bales at feeding minus the weight of refused forage. Forage intake was calculated using oven DM determinations at 60°C for 72 h (Bates, 1989b). Gross energy intake was measured with cattle, but DE intake was estimated using GE digestibility data from sheep. The ME intake was calculated by multiplying DE by 0.82 (NRC, 1984).

The results of these experiments were analyzed as a complete randomized design (4 treatments, 2 replicates). The mean values for the pens for each treatment were used in the analyses. The seven degrees of freedom were partitioned between treatments (3 df) and random error (4 df). The ANOVA model for voluntary DM intake was as follows:

$$Y_{ij}=\mu+T_i+\epsilon_{ij}$$

where

Y_{ij} = voluntary DM intake.

μ = overall mean.

T_i = fixed effect of treatment and

ϵ_{ij} = random residual error.

Performance

Liveweight changes were calculated as full average daily gain, shrunk average daily gain and adjusted average daily gain. The full average daily gain and shrunk average daily gain for each animal were calculated as the difference between initial and final full or shrunk weights divided by the number of feed days of the trial. Gut fill of steers in experiment 1 was determined as the difference between the full weight of the digestive tract and the empty tract weight. The adjusted average daily gain of heifers in experiment 1 and 2 was calculated as the difference between initial full weight and the adjusted final full weight divided by the number of feed days. At the end of the trials cattle from all treatments were placed in one group and fed hay. After 19 days in experiment 1, or 18 days in experiment 2, a full weight was taken on all cattle. The adjusted full weight of each animal in a pen was calculated as the deviation of the pen full weight (end of trial compared to 19 or 18 days later) from the deviation across all pens.

The average daily gains were analyzed by analysis of variance using general linear model procedure according to a complete randomized design; the seven degrees of freedom were partitioned between treatments (3) and random variation due to pens in the same treatments. The treatment means were compared for significance by the non orthogonal t-tests. The ANOVA model was as follows:

$$Y_{ij}=\mu+T_i+\epsilon_{ij}$$

Y_{ij} = average daily gain.

μ = overall mean.

T_i = fixed effect of treatment and

ϵ_{ij} = residual random error due to differences in pens in the same treatment.

Digestibility and Nitrogen Balance

Twenty four wethers in experiment 1 and twenty four Suffolk-Rambouillet lambs in experiment 2 were used to determine the digestibility of the forages. Nitrogen balance was also determined in experiment 2. The sheep averaged 35 kg in experiment 1 and 29 kg in experiment 2 and were assigned randomly to the treatments (six sheep/treatment) and to pens. The assigned forage diets were fed for a 13-day standardization period followed by a 7-day collection period.

The animals were confined to the individual pens during the trial with free access to water and minerals. The experimental diets were fed to maintain bodyweight (1.8% of body weight).

In both experiments, feces were collected in fecal bags, and in experiment 2, total daily urine voided was collected in buckets containing 65 ml of 75% HCL to prevent NH_3-N loss. Proportionate samples of urine (10%), feces (20%) and feed offered and total amount of orts were collected daily and frozen. Urine and fecal samples were composited within animals over the seven day collection period. Feed samples and orts were composited within treatment over the seven days period. The weights of feces, urine and orts were recorded daily.

The apparent digestibility of the DM, OM, CP, NDF and energy was calculated according to conventional methods (Schneider and Flatt, 1975). Digestibility and nitrogen balance data were analyzed by least squares analysis of variance using a completely randomized design. The ANOVA model for a single year was

$$Y_{ij}=\mu+T_i+\epsilon_{ij}$$

where

Y_{ij} = per cent digestibility of a nutrient (N retention),

μ = overall mean,

T_i = fixed effect of treatment and

ϵ_{ij} = random residual error.

Analytical Procedures

At baling and feeding, four core samples of forage were removed from each bale using a Penn State core sampler and were placed into plastic bags, sealed and frozen until analyzed.

Forage DM was determined by oven drying at 60°C for 72 h (Bates et al., 1989a) and ground through a 1 mm screen. Ground samples were dried at 105°C for DM determination. Organic matter was determined after ashing at 550°C. Ash-free NDF (NDFA) was determined as outlined by Goering and Van Soest (1970). The residue were filtered using gooch crucibles with glass wool mats (Moore and Mott, 1974) and ashed. The weight of NDFA was estimated as the difference between the weights of crucibles containing residues dried overnight at 105°C and those ashed for 3 h at 550°C. In vitro organic matter digestibility (IVOMD) was determined on the samples dried at 60°C as outlined by Moore and Mott (1974). Frozen samples of forages and feces were ground with dry ice in a Vitamix 4000 (Waldo, 1978) and analyzed for DM and GE. An aqueous extract of silage was prepared by the method of Parker (1978) and analyzed for pH, and volatile fatty acids (VFA; i.e., acetate and butyrate) and lactate. Kjeldahl N was determined using a block digester and an adaptation of the Technicon Auto Analyzer (Technicon, Tarrytown, NY) with values converted to CP by multiplying %N x 6.25. Ammonium-N was determined using an adaptation of the Technicon Auto Analyzer (Technicon, Tarrytown, NY) of the ammonia-salicylate reaction (Noel and Hambleton, 1976). A pH meter (Corning Model 12 Research pH meter, Corning scientific Instruments, Medfield, MA) with a calomel electrode was used to determine pH of the aqueous silage extract (Parker, 1978).

Acetate and butyrate produced by the fermentation of bermudagrass were analyzed by gas chromatography (Supelco, Inc., 1975). A five ml aliquot of each sample was acidified with 1 ml 25% m-phosphoric acid and filtered through a .4 μm filter (Gelman Sciences Inc., Ann Arbor, MI). Samples were analyzed on a Perkin Elmer Sigma 3B gas chromatograph (Perkin-Elmer, Norwalk, CT) with a flame ionization detector. The chromatographic column was a 183 cm x .6 cm glass column packed with 10% SP-100/1% H_3PO_4 on 100/120 chromosorb W AW (Supelco, Inc., Bellefonte, PA). Duplicate 1 μl samples of acidified aqueous extract were injected automatically into the chromatograph and peak areas were compared to external standards. Peak areas were calculated using a Perkin-Elmer LC-100 computing integrator (Perkin-Elmer, Norwalk, CT). Millimolar concentrations of acetic, propionic and butyric acids of the diluted silage extract were determined.

Lactic acid was also analyzed by gas chromatography (Supelco, Inc. 1975). A 5 ml sub-sample of the aqueous silage extract was acidified with a 1 ml 25% m-phosphoric acid, filtered through a .4 μm filter and methylated following the procedures outlined by Holdeman et al. (1977). Samples were analyzed on the same chromatographic column used for the volatile fatty acids.

The GE of undried forage, feces and orts was determined in a Parr bomb calorimeter (Parr model 1261 Isoperibol Calorimeter, Parr Instrument Company, Moline, IL) and polyethylene glycol was used as a primer. The GE concentration of the polyethylene glycol and the mixture (sample-polyethylene glycol) were determined and GE of the sample was computed as the difference between the GE of the mixture and the GE of the primer.

Results and Discussion

Storage Losses

The recovery of DM and GE of round bale forages of bermudagrass following the storage period are presented in Table 3.1. In experiment 1, unwilted and 1 to 2 h-wilted bermudagrass silage had similar ($P>.05$) DM recovery (85.26 and 86.75%), but had a lower DM recovery ($P<.05$) than hay (97.02%). Wilting bermudagrass for 2 to 4 h resulted in higher ($P<.05$) DM recovery (90.56%) than unwilted silage, but lower DM recovery ($P<.05$) than hay. The GE recovery in experiment 1 was higher ($P<.05$) for hay (97.67%) than wilted silages which averaged 88.97% GE recovery. The GE recovery of unwilted silage (91.71%) was not different from the GE recovery of wilted silages or hay.

In experiment 2, DM recovery of hay (97.09%) was higher ($P< .05$) than that of silages which were 89.14, 90.31 and 91.86%, respectively, for unwilted, 1 to 2h-wilted and 2 to 4h-wilted silages. The GE recovery was similar ($P=.42$) for hay and silages and averaged 93%.

Storage losses of DM ranged from 11 to 15% for unwilted round bale silage, 10 to 13% for 1 to 2 h-wilted silage, 8 to 9% for 2 to 4 h-wilted silage and 3% for hay. These results are similar to observations of Savoie and Marcoux (1985) who reported 14.8% and 10.1% DM losses for unwilted and wilted silages, respectively. Belyea et al. (1985) reported DM losses during storage of 2% for round bale hay stored inside.

The GE losses for both experiments varied from 5 to 8% for unwilted silage, 9 to 12% for 1 to 2h-wilted, 8 to 10% for 2 to 4h-wilted silages and 2 to 5% for hay stored inside. The DM recovery of

Table 3.1. Effect of Wilting on Dry Matter and Gross Energy Recovery at Feeding. Growing Cattle Experiments.

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
DM, %	85.26^a	86.75^{ab}	90.56^b	97.02^c	1.78	.001
Gross energy, %	91.71^{ab}	88.40^a	89.54^a	97.67^b	2.42	.045
Experiment 2						
DM, %	89.14^a	90.31^a	91.86^a	97.09^b	1.63	.012
Gross energy, %	94.71	90.77	92.34	95.08	2.03	.422

Note: Means and standard errors for n=12.

[a,b,c] Means in the same row with different superscripts differ ($P<.05$) using T-test.

the unwilted silage may be underestimated because of losses of volatilecompounds (i.e., VFA, alcohol, etc.) during the oven drying process (Waldo, 1977).

Composition of Forages

The composition and IVOMD of forages at harvesting and feeding are presented in Tables 3.2 and 3.3. In experiment 1, wilting for 1 to 2 h increased ($P<.01$) DM concentration from 26.1 to 36.7% at harvest, whereas wilting for 2 to 4 h increased DM concentration from 26.1 to 51.9%. The OM concentration of 1 to 2h-wilted, 2 to 4h-wilted forages and hay was higher ($P<.01$) than that of unwilted forage at both harvest and feeding. The CP concentrations among forages were different ($P<.01$) at harvest, but similar at feeding. At harvest, the IVOMD of forages ranged from 47.0% for 1 to 2h-wilted silage to 50.6% for 2 to 4h-wilted silages; however, at feeding the 2 to 4h-wilted silage and hay had 46.7% and 47.9% IVOMD compared to 1 to 2h-wilted and unwilted which had 42.8% and 42.4% IVOMD, respectively. The NDF concentration of hay was higher ($P<.05$) than that of silages all of which had similar NDF concentrations. At harvest, the GE concentration of unwilted, wilted forages and hay did not differ ($P=.482$). At feeding, the GE concentration of unwilted silage was higher ($P<.01$) than that of wilted silages or hay which had similar GE concentrations.

In experiment 2, wilting also increased DM concentration of forages at both harvesting and feeding (Table 3.3). At harvest, wilted silages had higher ($P<.01$) GE concentrations than unwilted forages and hay, both of which had similar GE concentrations. The GE concentrations

Table 3.2. Effect of Wilting on Characteristics of Forages. Growing Cattle Experiment 1

Item	Wilting time None	 1 to 2h	 2 to 4h	Hay	S.E.	P
At Harvest						
DM, %	26.1^{a}	36.7^{b}	51.9^{c}	86.7^{d}	2.01	.001
Organic matter, %DM	94.0^{a}	94.5^{b}	94.3^{b}	94.5^{b}	0.11	.004
Crude protein, %DM	14.5^{a}	15.6^{b}	13.3^{c}	15.9^{b}	0.28	.001
Gross energy, kcal/g DM	4.46	4.41	4.55	4.48	0.08	.482
IVOMD, %	49.1^{ef}	47.0^{e}	50.6^{f}	49.9^{f}	0.79	.020
At Feeding						
DM, %	23.8^{a}	34.4^{b}	50.1^{c}	88.3^{d}	1.24	.001
Organic matter, %DM	92.6^{a}	93.9^{b}	93.9^{b}	94.3^{b}	0.23	.001
Crude protein, %DM	14.8	14.6	14.4	14.4	0.24	.540
Gross energy, kcal/g DM	4.80^{a}	4.47^{b}	4.49^{b}	4.49^{b}	0.08	.001
IVOMD, %	42.4^{e}	42.8^{e}	46.7^{f}	47.9^{f}	0.76	.001
NDF, %DM	69.5^{e}	71.1^{e}	70.9^{e}	82.3^{f}	0.48	.001

Note: Means and standard errors for n=12.

^{a,b,c,d}Means in the same row with different superscripts differ (P<.01) using T-test.

^{e,f}Means in the same row with different superscripts differ (P<.05) using T-test.

Table 3.3. Effect of Wilting on Characteristics of Forages. Growing Cattle Experiment 2

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
At Harvest						
DM, %	31.3^{a}	38.7^{b}	48.6^{c}	76.4^{d}	1.50	.001
Organic matter, %DM	92.9^{a}	92.9^{a}	93.5^{ab}	93.8^{b}	0.25	.066
Crude protein, %DM	14.3^{a}	13.9^{a}	12.1^{b}	14.2^{a}	0.50	.011
Gross energy, kcal/g DM	4.32^{e}	4.60^{f}	4.51^{f}	4.29^{e}	0.06	.001
IVOMD, %	51.2^{a}	49.1^{bc}	51.0^{ab}	48.6^{c}	0.73	.024
At Feeding						
DM, %	28.4^{a}	36.3^{b}	45.1^{c}	86.4^{d}	1.69	.001
Organic matter, %DM	92.4^{a}	92.5^{a}	93.7^{b}	93.7^{b}	0.29	.002
Crude protein, %DM	13.2^{a}	13.6^{a}	13.5^{a}	12.3^{b}	0.20	.001
Gross energy, kcal/g DM	4.63^{e}	4.53^{e}	4.59^{e}	4.18^{f}	0.06	.001
IVOMD, %	41.7^{e}	43.4^{ef}	46.0^{f}	43.6^{ef}	1.03	.042
NDF, %DM	68.7^{e}	69.5^{e}	68.8^{e}	82.5^{f}	0.72	.001

Note: Means and standard errors for n=12.

[a,b,c,d] Means in the same row with different superscripts differ (P<.01) using T-test.

[e,f] Means in the same row with different superscripts differ (P<.05) using T-test.

of silages at feeding were similar (P>.05), but higher (P<.05) than that of hay. At harvest, OM concentration of hay was higher (P<.01) than that of unwilted and 1 to 2h-wilted forages which had OM concentrations similar (P=.06) to 2 to 4h-wilted forage. At feeding, 2 to 4h-wilted silage and hay had higher (P<.01) OM than unwilted and 1 to 2h-wilted silages. The CP concentration at harvest of 2 to 4h-wilted forage was lower (P<.01) than that of other forages. At feeding, CP concentrations of silages were similar, but were higher (P<.01) than that of hay.

The unwilted forage at harvest had IVOMD similar to 2 to 4h-wilted forage, but had higher (P<.01) IVOMD than 1 to 2h-wilted forage and hay both of which had similar IVOMD. At feeding, 2 to 4h-wilted silage had IVOMD similar to 1 to 2h-wilted silage and hay, but had higher IVOMD (P<.05) than unwilted silage. In experiment 1, the reduction in IVOMD from harvesting to feeding was 13.6% for the unwilted silage, 8.9% for the 1 to 2h-wilted silage, 7.7% for the 2 to 4h-wilted silage and 4.0% for hay. In experiment 2, IVOMD was reduced by 18.6% for the unwilted silages, 11.6% for the 1 to 2h-wilted silage, 9.8% for the 2 to 4h-wilted silage and 10.3% for the hay. In both experiments, 2 to 4h-wilted silage and hay tended to have higher IVOMD at feeding than did unwilted and 1 to 2h-wilted silages. Gordon (1981) reported a reduction of 2 percentage units in digestible organic matter (DOM) of silage after a 24 to 48 h wilting period. Haigh and Parker (1985) reported a reduction of 1% in DOM of silages following a wilting period of 24 to 48 h. Both of these studies were done with cool season grasses using a wilting period of 24 h or more.

The findings of this study showed that wilting for 2 to 4 h improved the OM digestibility of silages. Umuna et al. (1990) reported an increase in IVOMD of bermudagrass as a result of wilting bermudagrass for 1 h.

Fermentation Characteristics of Silages

The fermentation characteristics of silages are given in Table 3.4. The pH of all silages for both experiments was above the theoretical pH value of 4 to 4.2 needed to prevent secondary fermentation (Weissbach et al., 1974). The pH of the 2 to 4h-wilted silage (6.70) in experiment 1 was higher ($P<.01$) than that of unwilted and 1 to 2h-wilted silages. In experiment 1, wilted silages contained less ($P<.05$) ammonia-nitrogen, acetic and butyric acids than unwilted silage. Ammonia-nitrogen was higher ($P<.05$) in 1 to 2h-wilted silage than 2 to 4h-wilted silage.

In experiment 2, the pH of wilted silages tended to be higher ($P<.065$) than that of unwilted silage. Ammonia-nitrogen concentration was similar for wilted silages, but lower ($P<.01$) than that of unwilted silage. Lactic acid concentration and acetic acid concentration were higher ($P<.01$) for unwilted silage than for wilted silages, both of which had similar fermentation acid concentrations.

Intake and Liveweight Change of Growing Cattle

Forage intakes in experiments 1 and 2 are given in Table 3.5. In experiment 1, increasing DM concentration from wilting for 2 to 4 h increased daily DM intake per 100 kg body weight (BW) by 19% compared to the unwilted silage. The increased intake per 100 kg BW for 2 to 4h-wilted silage was 17.4%. The 2 to 4h-wilted silage and hay had similar

Table 3.4. Effect of Wilting on Dry Matter Concentration and Fermentation Characteristics of Silages. Growing Cattle Experiments

	Wilting time				
Item	None	1 to 2h	2 to 4h	S.E.	P
Experiment 1					
DM, %	24.5^a	32.0^b	48.8^c	0.71	.001
pH	5.57^a	5.43^a	6.70^b	0.18	.001
NH_3-N, % Total N	10.20^d	8.40^e	3.32^f	0.47	.001
Lactic acid, %DM	1.09	0.64	0.46	0.51	.660
Acetic acid, %DM	1.48^a	0.69^b	0.17^c	0.14	.001
Butyric acid, %DM	0.32^a	0.17^b	0.03^b	0.06	.005
Experiment 2					
DM, %	28.4^a	36.7^b	44.6^c	1.72	.001
pH	5.42	5.69	5.79	0.11	.065
NH_3-N, % Total N	10.70^a	8.10^b	6.10^b	0.87	.001
Lactic acid, %DM	1.34^a	0.13^b	0.15^b	0.30	.011
Acetic acid, %DM	1.16^a	0.28^b	0.25^b	0.10	.001
Butyric acid, %DM	0.08	0.03	0.09	0.04	.463

Note: Means and standard errors for n=12.

[a,b,c] Means in the same row with different superscripts differ (P<.01) using T-test.

[d,e,f] Means in the same row with different superscripts differ (P<.05) using T-test.

DM intakes. There were higher (P<.05) DE and ME intakes when silage was wilted for 2 to 4 h. In experiment 2, DM intakes of wilted forages were similar (P=.31) and averaged 1.80% of BW, but the increased intake of 2 to 4h-wilted silage was only 9% compared to unwilted silage. In both experiments, 1 to 2 h and 2 to 4 h wilting increased DM concentration, and there was a linear relationship between silage DM intake and DM concentration as shown in Figures 3.1 and 3.2.

Liveweight change of cattle fed bermudagrass round bale forages are given in Table 3.6. In experiment 1, growing cattle fed hay had full liveweight gains (320 g/day) similar (P>.05) to that of growing cattle fed 2 to 4h-wilted silage (150 g/day). Growing cattle fed 2 to 4h-wilted silage had higher (P<.05) daily gain than growing cattle fed unwilted silage when performances were expressed as full average daily gain (ADG), shrunk ADG or adjusted ADG. Growing cattle fed unwilted silage lost 30 g/d (adjusted ADG) as opposed to growing cattle fed the 1 to 2h-wilted and 2 to 4h-wilted silages which gained respectively 70 g/d (adjusted ADG) and 160 g/d (adjusted ADG), respectively. Growing cattle fed hay had higher (P<.05) adjusted weight gains (240 g/d) than growing cattle fed unwilted and 1 to 2h-wilted silages. Height and body condition score changes followed those of weight changes.

In experiment 2, adjusted weight losses for growing cattle fed unwilted and 1 to 2h-wilted were 100 g/d and 60 g/d, respectively, while the 2 to 4h-wilted silage and the hay groups gained 70 and 20 g/d, respectively. Dry matter intake expressed as kg per 100 kg bodyweight ranged from 1.66 kg for unwilted silage to 1.78, 1.81 and 1.65 kg for 1 to 2h-wilted, 2 to 4h-wilted and hay, respectively.

Table 3.5. Effect of Wilting on Forage Intake. Growing Cattle Experiments

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
Average shrunk weight, kg	250^{a}	251^{a}	253^{ab}	266^{b}	3.50	.099
DM, kg/day	4.17^{a}	4.62^{ab}	4.95^{b}	4.99^{b}	0.20	.115
Feeding losses, % DM fed	8.7	9.2	13.0	7.2	2.95	.596
DM intake, g/kg $BW^{0.75}$	66.3^{a}	73.2^{ab}	78.1^{b}	75.9^{b}	2.54	.107
DM intake, kg/100 kg BW	1.67^{a}	1.84^{ab}	1.96^{b}	1.88^{ab}	0.06	.103
GE intake, kcal/kg $BW^{0.75}$	318	328	349	310	11.1	.214
DE intake, kcal/kg $BW^{0.75}$	161^{a}	158^{a}	177^{b}	164^{ab}	5.50	.127
ME intake, kcal/kg $BW^{0.75}$	132^{a}	129^{a}	145^{b}	135^{ab}	4.50	.127
Experiment 2						
Average shrunk weight, kg	219	228	238	238	6.90	.152
DM intake, kg/day	3.62^{a}	4.05^{bc}	4.31^{b}	3.94^{c}	0.07	.011
Feeding losses, % DM fed	11.5^{a}	16.2^{ab}	20.5^{b}	17.7^{ab}	1.86	.103
DM intake, g/kg $BW^{0.75}$	63.7	69.1	69.4	64.9	1.58	.137
DM intake, kg/100 kg BW	1.66	1.78	1.81	1.65	0.05	.314
GE intake, kcal/kg $BW^{0.75}$	292^{a}	308^{a}	314^{a}	248^{b}	7.00	.008
DE intake, kcal/kg $BW^{0.75}$	150^{a}	157^{ab}	164^{b}	127^{c}	2.80	.007
ME intake, kcal/kg $BW^{0.75}$	123^{a}	129^{ab}	134^{b}	104^{c}	2.30	.007

Note: Means and standard errors for n=2;

^{a,b,c}Means in the same row with different superscripts differ (P<.05) using T-test.

Table 3.6. Effect of Wilting on Liveweight Change. Growing Cattle Experiments

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
Initial shrunk weight, kg	253	246	248	253	6.8	.835
Daily gain, kg						
Full	-0.10^{a}	0.05^{ab}	0.15^{bc}	0.32^{c}	0.05	.019
Shrunk	-0.10^{a}	0.05^{ab}	0.12^{b}	0.30^{c}	0.05	.018
Adjusted	-0.03^{a}	0.07^{ab}	0.16^{bc}	0.24^{c}	0.03	.017
Height change, cm	0.46^{a}	2.11^{b}	2.18^{b}	2.54^{b}	0.43	.005
Condition score change	-1.95^{a}	-1.50^{b}	-1.15^{bc}	-0.70^{c}	0.15	.019
Experiment 2						
Initial shrunk weight, kg	226	232	236	237	4.09	.369
Daily gain, kg						
Full	-0.12^{a}	-0.06^{ab}	0.06^{b}	0.05^{b}	0.05	.125
Shrunk	-0.20^{d}	-0.09^{d}	0.04^{e}	0.02^{e}	0.03	.012
Adjusted	-0.10^{a}	-0.06^{a}	0.07^{b}	0.02^{b}	0.02	.018
Height change, cm	1.68	2.46	2.41	2.82	0.43	.404
Condition score change	-1.15	-0.90	-0.45	-0.95	0.28	.457

Note: Means and standard errors for n=2;

^{a,b,c}Means in the same row with different superscripts differ ($P<.05$) using T-test.

^{d,e}Means in the same row with different superscripts differ ($P<.01$) using T-test

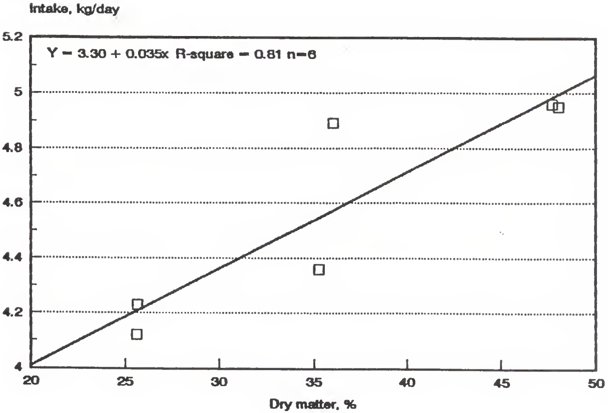

Figure 3.1. Effect of Dry Matter Concentration on Silage Intake. Growing Cattle Experiment 1.

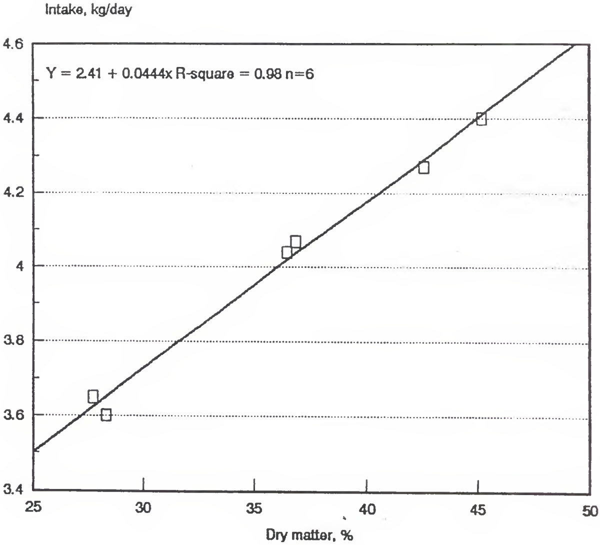

Figure 3.2. Effect of Dry Matter Concentration on Silage Intake. Growing Cattle Experiment 2.

For both experiments, wilting resulted in increased daily forage intake. The increased intake of wilted silage for growing cattle ranged from 12% to 19% which is similar to the increased intake of 19% reported by Haigh and Parker (1985) with a mixture of ryegrass and white clover. Marsh (1979) and Zimmer and Wilkins (1984) reported a 25 to 31% increase in intake as a result of wilting. Flynn and Wilson (1978) concluded that increased intake with wilted silages occurred only when unwilted silage was badly preserved. Waldo (1977) reported that unwilted silage had only 75% of the intake of hay. Intake of hay (kg/day) in the second experiment of this research was only 9% higher than that of the unwilted silage; the forage was more mature (6-7 weeks of regrowth) and drier than the forage used in experiment 1 (5 to 6 weeks regrowth).

Adjusted daily liveweight change of heifers fed 2 to 4h-wilted silage (+160 g) tended to be higher than that of 1 to 2h-wilted silage (70 g) in experiment 1, but was not different from hay (240 g) when expressed as adjusted full weight. Animals fed wilted forages tended to have higher fill (Figure 3.3) than those fed unwilted silage. Differences in fill do not fully account, however, for differences in liveweight change. In experiment 2, the heifers fed both unwilted and 1 to 2h-wilted silages lost weight while heifers fed the 2 to 4h-wilted silage had similar adjusted liveweight gain as animals fed hay (70 g/d vs 20 g/d). The average daily DM intakes for the two experiments were 4.63 kg/day and 4.47 kg/day for 2 to 4h-wilted silage and hay, respectively. The average adjusted daily gains for the two experiments were 115 g/day and 130 g/day for the 2 to 4h-wilted silage and hay, respectively.

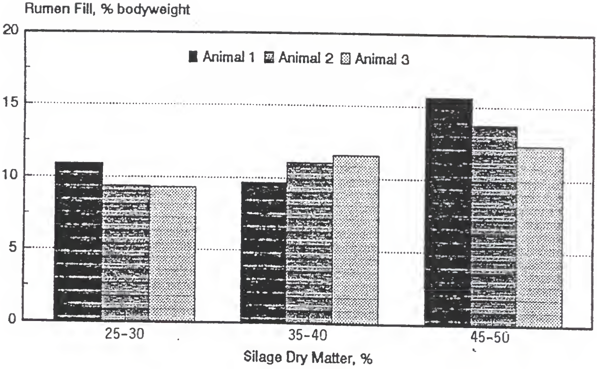

Figure 3.3. Effect of Silage Dry Matter Concentration on Rumen Fill.

The DM of hay and 4h-wilted silage required for a 1 kg liveweight gain were 34 and 40 kg DM suggesting a better utilization of nutrients from hay than silages. Charmley and Thomas (1987) reported liveweight gains of +55 g/day and empty body weight gains of +64 g/d for steers fed wilted silages. Haigh and Parker (1985) also reported higher liveweight gains of steers fed wilted silages than steers fed unwilted silage.

Granier and Razafindratsita (1971) reported an increase in milk production of the order of 25% with a wilted tropical grass as compared to the same forage fed unwilted. Previous research on the effects of wilting on animal production have not been consistent. It is difficult, however, to draw conclusive results from past research because of variation in period of wilting, forage species and environmental conditions. Berthilson (1987) concluded that wilting improves silage fermentation, intake and animal performance only when climatic conditions for wilting are favorable.

Digestibility

Data related to the digestion of nutrients in silages and hay used in experiments 1 and 2 are given in Table 3.7. The digestibility of nutrients of the stored forages was determined in sheep. In experiment 2, the unwilted silage had lower ($P<.05$) digestibility of DM and OM than did the wilted silages and hay. In Experiment 1, GE digestibility was not affected by treatment ($P=.179$). In experiment 1, CP digestibility of wilted silages (68.4%) was higher ($P<.05$) than that of hay, but not different from to that of the unwilted silage (63%).

In experiment 2, GE digestibility was similar ($P>.05$) for all

Table 3.7. Effect of Wilting on the Digestibility of Nutrients. Sheep Experiments

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
Dry matter, %	43.7	47.7	46.3	45.8	1.54	.341
DM intake, kg/day	0.75	0.85	0.89	0.82	0.06	.428
Organic matter, %	44.4	48.5	47.6	47.0	1.48	.272
Neutral detergent fiber, %	41.0	45.0	45.3	43.5	1.91	.401
Gross energy, %	50.4	53.0	48.1	50.8	1.50	.179
Crude protein, %	63.0^{ab}	68.7^{b}	68.1^{b}	58.0^{a}	2.40	.016
Experiment 2						
Dry matter, %	41.0^{a}	47.0^{b}	48.0^{b}	47.1^{b}	1.81	.056
DM intake, kg/day	0.39^{a}	0.46^{ab}	0.44^{ab}	0.52^{b}	0.03	.029
Organic matter, %	45.0^{a}	50.0^{b}	50.4^{b}	49.2^{b}	1.73	.108
Neutral detergent fiber, %	41.0	42.2	45.0	44.2	2.69	.687
Gross energy, %	51.4	51.0	52.1	51.0	1.44	.916
Crude protein, %	63.1^{a}	53.8^{b}	60.9^{ab}	43.1^{c}	3.32	.001

Note: Means and standard errors for n=6, except for crude protein.

^{a,b}Means in the same row with different superscripts differ ($P<.05$) using T-test.

treatments and averaged 51%. The CP digestibilities of wilted silages were similar and higher (P<.05) than that of hay. The 1 to 2h-wilted silage had a lower (P<.05) CP digestibility than unwilted silage. These results contrast with the results of Grant et al. (1974) who reported that wilting increased digestibility of napiergrass silage. They argued that some chemical and enzymatic changes occur within the plant during ensiling which caused an increase in digestibility of the cell wall. In contrast, several studies have reported that wilting decreased OM and GE digestibility (Charmley and Thomas, 1989; Haigh and Parker, 1985; Steen, 1985). Losses of highly digestible nutrients through oxidation and leaching will be high if the period of wilting is longer than 24 h and under poor weather conditions (McDonald, 1981).

Waldo (1978) suggested that DM or OM digestibility may be biased because of possible analytical errors due to losses of volatiles during the drying of highly fermented (low DM) silages. From the results of experiments 1 and 2, it can be concluded that wilting improved the digestibility of DM and OM relative to unwilted direct-cut silages; but digestibility of GE is not improved.

Nitrogen Utilization

Nitrogen utilization of bermudagrass forages by sheep for experiment 2 is given in Table 3.8. Nitrogen intake was similar for all treatments. Fecal N was higher (P<.05) for 1 to 2h-wilted groups and hay groups than the unwilted group. The absorbed N was similar for silages groups and was higher (P<.05) than that for hay groups.

Table 3.8. Effect of Wilting on Nitrogen Utilization.
Sheep Experiment 2

Item	Wilting time					
	None	1 to 2h	2 to 4h	Hay	S.E.	P
Nitrogen, g/day						
Intake	7.05	8.12	7.29	6.88	0.45	.206
Fecal	2.60^{a}	3.67^{bc}	2.86^{ab}	3.97^{c}	0.31	.012
Absorbed	4.44^{a}	4.45^{a}	4.43^{a}	2.91^{b}	0.37	.017
Urinary	7.07^{a}	6.45^{a}	4.45^{b}	3.20^{b}	0.71	.002
Retention	-2.63^{a}	-2.00^{ab}	-0.02^{b}	-0.29^{b}	0.78	.050
Urinary N:N absorbed, %	160.3^{a}	159.0^{a}	101.5^{b}	109.6^{ab}	19.8	.060

Note: Least squares means (n=6 for silages, n=5 for hay) and standard errors for hay (n=5)

^{a,b,c,d}Means in the same row with different superscripts differ ($P<.05$) using T-test.

Urinary N excretion for unwilted and 1 to 2h-wilted silage groups was higher ($P<.05$) than for 2 to 4h-wilted and hay groups. Wilted silages and hay had similar N retention, but 2 to 4h silage and hay groups had higher N retention ($P<.05$) than did the unwilted silage groups. The amount of urinary N as percent of absorbed N was was lower ($P<.05$) for the 2 to 4h-wiltedsilage group than for unwilted and 1 to 2h-wilted silage groups, but was similar to that of hay group.

In experiments 1 and 2 the digestibilities of CP of wilted silages were similar, but higher than that of hay. The lower apparent CP digestibility of hay compared to that of silages agreed with previous reports of Merchen and Satter (1983) and Atwal (1983) who compared alfalfa hay and silage. Beever et al. (1971b), however, indicated that drying the forage depressed N retention.

The higher N retention for 2 to 4h-wilted silage and hay groups than the unwilted group suggests a higher efficiency of N utilization for these forages than for the unwilted silage. Hay and wilted silage groups excreted less N in urine than unwilted and 1 to 2h-wilted silage groups. The higher solubility of the N of unwilted silage, as indicated by higher ammonia-N concentration, may explain differences in urinary N. Thomson and Beever (1981) reported that ensiling led to a reduction in forage amino acids in grass from 79% of the N in the original crop to 50-55% for the two silages, while the flow of amino acids N at the duodenum was 15% lower for unwilted silage and 25% lower for wilted silage compared to the fresh crop. Differences in N utilization between the fresh crop, unwilted and wilted silages were attributed to differences in fermentable carbohydrates, the level of degraded N being assumed similar.

General Discussion

Conservation of high moisture tropical grasses as stretch-wrapped round bale silage allows the harvest of a nutritious crop when the plant is young and leafy and when the weather is humid. Field losses attributable to respiration, leaf shatter and leaching by rain, and losses during storage attributable to oxidation, fermentation and effluent contribute towards a decrease in forage quantity and quality following harvest. Ensiling reduced field losses and the increased DM concentration at harvest due to wilting decreased DM losses during storage, but wilting did not improve GE recovery. Storage losses may result from extensive fermentation of plant WSC. Lower DM losses due to wilting may be associated with restricted fermentation of plant substrates.

Fermentation of WSC and protein degradation by plant and bacterial enzymes decrease the quality of silage. With hay, extensive respiration losses and weathering may also contribute to a reduction in WSC and CP. Consequently, the fiber concentration of conserved forages (silages and field-cured hay) may increase while the OM and CP concentrations of forages may decrease. Jarrige et al. (1984) reported a decrease in CP concentration of 0.6% for a field dried hay in good weather and 0.3% for silage wilted to 30 to 35% DM. The increase in fiber concentration for these forages was +1.6% and +0.9%, respectively.

In this study, the OM concentrations of 1 to 2h-wilted, 2 to 4h-wilted and hay were higher than that of unwilted silages.

Also, the NDF fraction of hay was greater than that of the silages. Jarrige et al. (1984), based on several publications, reported an increase of 9.1% percentange units in crude fiber (CF) concentration of hay relatively to fresh forage. In contrast, the change in CF concentration of silages was negligible (0.9%). Oven drying of highly fermented forages will result in underestimation of DM associated with loss of volatile compounds (Waldo, 1966). The higher IVOMD of wilted silages and hay than that of unwilted silages contrasts with European data (Marsh, 1979) which show a depression in IVOMD for wilted silages and hay. Differences in residual WSC between wilted silages, hay and unwilted silages may explain differences in IVOMD between forages. More soluble N in unwilted silage may also result in reduced fiber digestibility because of an association with a high concentration of ammonia in the rumen. The magnitude and reduction in the OM digestibility of hays is closely related to DM losses during drying (Shepperson, 1960; Demarquilly and Jarrige, 1970a). The concentration of ammonia was higher in unwilted silages than in wilted silages.

The intake of conserved forages is also related to changes in nutrient concentration and quality during the conservation process. The increased intake of forage DM associated with wilting can be explained by a combined effect of a stabilized and restricted fermentation and conservation of digestible nutrients. The high concentration of ammonia and acetic acid in ensiled high moisture tropical forages may depress their intake (Catchpoole and Henzell, 1969). The exact mechanism regulating the intake of wet feeds is not known. It is widely believed that intake may be limited by the bulkiness of wet feed. There is evidence, however, that any limitation due to the bulk does not act through negative feedback from distension of the rumen (John and Ulyatt, 1987). The intake of unwilted silage may have been limited by the palatability of unwilted silages or by the capacity of cattle to eat unwilted silage. Wilted silages without perceptible reduction in DE or CP are associated with improved forage DM intake.

The potential of conserved forages for animal production is determined fundamentally by the intake of digestible nutrients. Depression in both voluntary DM intake and digestibility associated with the loss of DM and nutrients during fermentation will decrease the productivity of ruminants fed conserved forages. Zimmer (1976) concluded that the productivity of wilted silage (range 35 to 50% DM) is superior to direct cut silage and barn dried hay as a result of better DM recovery and higher intake. Chamberlain (1987) suggested that the presence of the end products of fermentation resulting from ensiling reduces the yield of ATP per unit of OM fermented in the rumen. The low yield of ATP from silage OM fermented in the rumen may reduce the production of microbial protein in the rumen. Ruminants depend on glucogenic amino acids, lactic acid, WSC and post-ruminal digested starch to synthesize glucose. Energy and protein interactions in the metabolism of the ruminant may also determine the intake of nutrients and the efficiency of utilization of nutrients. Thomas et al. (1984b) compared the response of beef cattle to increased digestibility with that achieved by enhancing the proportion of barley supplement. Higher gains were achieved by growing cattle fed silage of high digestibility. These steers consumed more ME, but their gains were lower than those achieved by animals fed a mixture of late cut silage and the high level of barley. More ME (20%) above maintenance was required by growing cattle fed early cut silage in order to achieve the same energy retention as those fed silage-concentrate diets. Liveweight gain of growing cattle fed wilted silages and hay confirmed the lower efficiency of utilization of nutrients from silage than hay. Leng and Preston (1976) and Preston and Leng (1986) suggested that glucose deficiency can be a constraint in animals consuming low quality forages. Low microbial protein yield and low residual WSC associated with silage diets may result in a low glucogenic potential of nutrients absorbed from silages.

CHAPTER IV
EFFECT OF FEEDING ROUND BALE BERMUDAGRASS SILAGES AND HAY ON THE PERFORMANCE OF COWS AND THEIR CALVES

Introduction

A major portion of the annual costs in many beef cow-calf operations is winter feed. Beef-forage producers face not only uncertainty in the quantity and quality of forage produced, but also production risk related to the conversion of forages to animal products. It has been suggested that the key to economical cow and calf production lies in improving the quality of forage and then by feeding more forage and less concentrates (Hoglund et al., 1954). Forage limitations affect production of a beef cow herd by (1) lowered reproduction, (2) lowered weaning weights, and (3) lowered stocking rates (Moore, 1977).

There has been considerable research on improving the efficiency of nutrient utilization. A combination of increased intake and greater digestible energy of the forage consumed, however, would be expected to increase animal performance. Harvesting and storing high-quality forage may decrease land requirements. Many forage harvesting, storing and feeding systems have been made available, but the costs vary with the system used. The interaction of forage quality and supplemental feeding on reproductive performance determines optimum management of beef cows during different seasons and productive stages. Cows that calve in late winter can use low-quality forages at certain times of the year. Jordan et al. (1968) reported that cows which accumulate enough body fat stores during the grazing season may lose body condition during the winter without adversely affecting reproduction.

Nutrient requirements are critical for cows between calving and breeding since peak lactation is reached near breeding time. Cows that are thin before and at calving have a long interval between calving and first estrus (Zimmerman et al., 1961; Hansen et al., 1982). Conception rates may be decreased if energy levels are below requirements at peak lactation (Dunn et al., 1969; Nicoll, 1979). Mature cows which lost 14% of mature weight produced as well as cows wintered so as to lose 10% of live mass (Pope, 1967). Wiltbank et al. (1964) found conception rates decreased when body condition scores fell below body condition score 5.0 during the winter. Kunkle et al. (1991), under Florida conditions, concluded that a body condition score of 5.0 at pregnancy testing was needed to achieve pregnancy rates above 90%.

The objective of this study was to compare performance of cows and their calves wintered on all-forage diets of round bale bermudagrass (including hay, silages wilted for 1 to 2h and 2 to 4 h, and unwilted silage).

Materials and Methods

Forage Management and Storage

The experiments were conducted during 1988-89 (experiment 1) and 1989-90 (experiment 2) at the University of Florida, Pines Acres

Research Farm, Citra, FL. A pasture dominated by Coastal bermudagrass (approximately 85% of the covered area) on Gainesville loamy fine sand was used. Other plant species included bahiagrass and some weeds. The sward was fertilized each year with 448 kg/ha (18-8-8) uniformly applied after each cutting. The grass was cut after 7 to 8 weeks of regrowth in the summer and mechanically conditioned using a New Holland model 848 baler. For the direct cut silage, the forage was cut and baled immediately at a dry matter concentration of 25 to 30%, then wrapped in a "stretch wrap" polyethylene film for storage. For the wilted treatments, the forage was wilted for 1 to 2 h to an estimated 35 to 40% DM or 2 to 4 h to an estimated 45 to 50% DM, then baled and wrapped with polyethylene. The grass harvested as hay was field-cured for 2 to 3 days and baled. All bales were weighed at harvest on an electronic scale. The plastic wrapped bales were stored in the field under trees to reduce sunlight exposure of the plastic. The round bales of hay were stored outside. After 3 to 7 months of storage all bales were weighed and every other bale was sampled at feeding.

Animal Management

Eighty eight pregnant beef cows from 3 to 11 years old were grouped according to breed, age and weight then randomly allocated to experimental groups and pens. The average weight of cows was 528 kg and 511 kg, respectively, for experiments 1 and 2. The initial body condition scores of cows for experiments 1 and 2 were 5.8 and 6.5, respectively. The experimental treatments were bermudagrass round bale silage unwilted, wilted for 1 to 2 h and for 2 to 4 h and bermudagrass round baled hay. Each diet was fed to two pens of 10 or 11 cows. The forages were fed to calving Angus, Brangus and Brahman cows during the winter from December 7 to March 9 for experiment 1 and December 4 to March 6 for experiment 2. Cows and calves were grazed on pasture from March until calves were weaned in September.

Cow weights, body condition score and calf weights were recorded in December at the beginning of the trial, in January, in March at the end of the experiment and during grazing after the feeding trial in June, August and September. The body condition scoring system used was 1 (thin) to 9 (fat) (Kunkle et al., 1991). The weights of calves were recorded at birth and each time the cows were weighed. Cow and calf weights and cow body condition scores and pregnancy status were also recorded at weaning in October or September.

The average DM content of round bales ranged from 162 kg for unwilted silages to 237 kg, 296 kg and 329 kg/bale for 1 to 2h-wilted, 2 to 4h-wilted and hay, respectively. The bales were fed ad libitum in round bale feeders. Visual estimates of refusals and forage wasted were made during the feeding period. The intakes of round bale forages were estimated as the difference between the total dry weight of forage offered during the trial and estimated feeding losses (wastage and refusals) divided by the total number of cows; this figure was then divided by the number of days of the trial (feed days).

Chemical Analyses

Samples of forages removed from selected bales at feeding were analyzed for forage characteristics which included DM, CP, IVOMD and OM.

The DM was determined on all samples by oven drying at 60°C for 72 hours (Bates et al., 1989b). For other analyses, the dried forage was ground through a 1mm screen. Aliquots of ground sample were dried at 105°C and OM was determined after ashing at 550°C. Kjeldahl N was determined using a block digester and an adaptation for the Technicon Auto Analyzer (Technicon, Tarryton, NY) with values converted to CP by multiplying %N x 6.25. The IVOMD was determined by incubating samples from the dried ground samples in vitro (Moore and Mott, 1974).

Statistical Analyses

The results of the experiments were analyzed as a complete randomized design. The seven degrees of freedom were partitioned between treatments (3 d.f.) and error (pen within treatments 4 d.f.). The ANOVA model for voluntary intake and cow and calf performance was as follows:

$$Y_{ij}=\mu+T_i+\epsilon_{ij}$$

where

Y_{ij} = voluntary intake or animal performance,

μ = overall mean,

T_i = fixed effect of treatment and

ϵ_{ij} = random residual error due to differences in pens in the same treatment.

Results and Discussion

Chemical Composition of Forages

The composition of forages at feeding is given in Table 4.1. Wilting successfully increased (P<.01) forage DM from 26.3 to 35.1 after 1 to 2 h wilting and from 35.1 to 48.9% after 2 to 4 h of wilting. In experiment 1, forage DM matter produced per bale increased (P<.01) from 162 kg DM to 239 kg DM for 1 to 2h-wilted silage and 294 kg for 2 to 4h-wilted silage. The average DM of forage per bale of hay (327 kg) was higher (P<.01) than that of silages because of larger bale size. The OM concentration of hay was higher (P<.01) than that of silages. The CP concentrations were similar (P=.02) for all treatments averaging 9.5%. Round bale bermudagrass forages had similar (P=.87) IVOMD averaging 39.6 in experiment 1.

In experiment 2, wilting also increased the DM concentration of forages. The OM concentration of 1 to 2h-wilted silage tended to be lower (P<.05) than that of unwilted silages and hay. The IVOMD of 1 to 2h-wilted silage (34.7) was lower (P<.05) than that of unwilted and 2 to 4h-wilted silages.

Intake of Forages

The intake of forages by cows for both experiments 1 and 2 is given in Table 4.2. In experiment 1, the estimated intake of unwilted silage (1.19% BW) was lower (P<.05) than that 1 to 2h-wilted silage (1.42%). The 2 to 4h-wilted silage and hay had similar DM intakes which averaged 1.52% and which were higher (P<.05) than 1 to 2h-wilted and unwilted silages.

Table 4.1. Forage Characteristics. Cow Experiments

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
Bale weight, kg	616^a	676^a	606^a	386^b	30.03	.001
Dry matter, %	26.3^a	35.1^b	48.9^c	85.1^d	1.21	.001
Bale dry matter, kg	162^a	239^b	294^c	327^d	17.26	.001
Organic matter, %DM	92.9^a	93.5^a	93.6^a	94.6^b	0.35	.001
Crude protein, %DM	10.15	9.64	10.14	9.06	0.39	.206
IVOMD, %	38.6	40.3	39.5	39.8	1.53	.870
Experiment 2						
Bale weight, kg	637^a	592^a	642^a	438^b	23.06	.001
Dry matter, %	29.2^a	39.9^b	46.5^c	85.0^d	1.32	.001
Bale dry matter, kg	186^a	236^b	296^c	372^d	10.69	.001
Organic matter, %DM	93.2^e	91.2^f	93.0^{ef}	94.4^e	0.67	.021
Crude protein, %DM	7.70^a	8.30^a	11.50^b	8.30^a	0.64	.001
IVOMD, %	39.4^a	34.7^b	40.6^a	39.5^{ab}	1.41	.029

Note: Means and standard errors for n=10 bales.

[a,b,c,d] Means in the same row with different superscripts differ (P <.01) using T-test.

[e,f] Means in the same row with different superscripts differ (P<.05) using T-test.

Table 4.2. Intake of Bermudagrass Round Bale Silages and Hay. Cow Experiments

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Experiment 1						
Forage DM, %	27.1[a]	39.3[b]	48.1[c]	83.3[d]	1.39	.001
Cow weight, kg[i]	489[a]	522[b]	490[a]	504[a]	6.84	.072
DM intake, kg/day	5.80[e]	7.40[f]	7.44[f]	7.72[f]	0.11	.001
DM intake, % BW	1.19[e]	1.42[f]	1.52[g]	1.53[g]	0.03	.002
Experiment 2						
Forage DM, %	29.6[a]	40.1[b]	44.9[c]	85.0[d]	1.99	.001
Cow weight, kg	484	492	494	508	10.3	.485
DM intake, kg/day	8.50	9.32	9.52	9.44	0.47	.481
DM intake, % BW	1.76	1.89	1.93	1.86	0.13	.814

Note: Means and standard errors for n=2.

[a,b,c,d] Means in the same row with different superscripts differ (P<.01) using T-test.

[e,f,g] Means in the same row with different superscripts differ (P<.05) using T-test.

[i] Average cow weight.

In experiment 2, the DM intake of all forages was similar (P=.81) and averaged 1.86% BW.

Performance of Cows and Calves

Weight change, body condition score change, pregnancy rate of cows and calf weight change and weaning weights are given in Tables 4.3 and 4.4 for experiments 1 and 2, respectively.

In experiment 1, cows fed unwilted and 2 to 4h-wilted silages had higher (P<.08) winter weight losses (-0.66 kg and -0.77 kg) than cows fed 1 to 2h-wilted silages (-0.20 kg) or hay (-0.31 kg). Cows in all treatments gained weight when grazing pasture after the trial. The weight gains tended to be higher for the unwilted and 2 to 4h-wilted groups of cows, suggesting a trend of compensation or that cows had less fill at the end of winter feeding phase in March. During the combined winter and summer periods, the weight changes were similar (P<.73) for all treatments.

In experiment 1, change in body condition score followed the same trend as liveweight change. At the beginning of the winter feeding trial the cows were in good body condition averaging 5.9. Body condition score losses of cows fed bermudagrass forages were higher (P<.07) for 2 to 4h-wilted and unwilted silage than that of 1 to 2h-wilted silage and hay. During summer when all cows were grazing similar pastures all treatments gained body condition, but cows fed unwilted and 2 to 4h-wilted silages gained more body condition than other treatments. Pregnancy rates were similar (P=.99) for all treatments and averaged 80%. Calf weight gains during the trial were

Table 4.3 Cow and Calf Performances on Bermudagrass Round Bale Silages and Hay. Cow Experiment 1

	Wilting time					
Item	None	1 to 2h	2 to 4h	Hay	S.E.	P
Cow weight change, kg/day						
Winter[c]	-0.66^{a}	-0.20^{b}	-0.77^{a}	-0.31^{b}	0.14	.083
Summer[d]	0.48^{a}	0.18^{b}	0.52^{a}	0.01^{b}	0.17	.076
Winter+summer	-0.07	-0.13	-0.10	-0.10	0.05	.725
Cow body condition score						
Initial	6.0	5.8	6.0	5.8	0.17	.574
Winter change	-1.00^{a}	-0.10^{b}	-1.10^{a}	-0.40^{b}	0.24	.073
Summer change	1.80^{a}	0.93^{b}	0.70^{a}	0.90^{b}	0.16	.028
Pregnancy rate, %	78.3	81.3	78.6	79.2	16.7	.999
Calf weight change, kg/day						
Winter	1.05	0.83	0.71	0.67	0.14	.372
Summer	1.09	1.06	0.99	1.10	0.04	.479
Weaning weight, kg	227	233	209	227	10.5	.429

Note: Means and standard errors for n=2.

[a,b] Means in the same row with different superscripts differ ($P<.05$) using T-test.

[c] Winter: December to March.

[d] Summer: March to September.

Table 4.4 Cow and Calf Performances on Bermudagrass Round Bale Silages and Hay. Cow Experiment 2

Item	Wilting time			Hay	S.E.	P
	None	1 to 2h	2 to 4h			
Cow weight change, kg/day						
Winter[a]	-0.60	-0.50	-0.23	-0.17	0.21	.484
Summer[b]	0.14	0.05	0.01	0.01	0.08	.583
Winter+ summer	-0.09	-0.11	-0.08	-0.06	0.04	.773
Cow body condition score						
Initial	6.2	6.4	6.5	6.7	0.19	.321
Winter change	-0.90	-1.13	-1.28	-1.27	0.25	.644
Summer change	1.32	0.99	0.66	1.00	0.28	.739
Pregnancy rate, %	76.4	78.9	66.8	77.2	7.8	.684
Calf weight change, kg/day						
Winter	0.74	0.70	0.71	0.62	0.12	.844
Summer	1.23	1.35	1.26	1.32	0.10	.808
Weaning weight, kg	224	221	212	218	8.7	.789

Note: Means and standard errors for n=2.

[a] Winter: December to March.

[b] Summer: March to September.

similar and ranged from 0.67 kg/day for hay to 0.71, 0.83, and 1.05 for 2 to 4h-wilted, 1 to 2h-wilted and unwilted silage, respectively. Weight change of calves during the summer and weaning weights were similar (P=.48 and P=.43, respectively) for all treatments.

In experiment 2, losses during the trial and weight gains on pasture following the trial were similar. Cows entered the winter with body condition score averaging 6.4 and lost 0.9 to 1.3 units of body condition score during the trial. When grazing pasture, they regained 0.7 to 1.3 units of body condition score. Pregnancy rates were similar (P=.68) for all treatments and ranged from 67% to 79%. Weight gains of calves were similar (P=.84 and P=.81 for winter and summer, respectively) for all treatments and averaged 0.69 kg/day during winter and 1.31 kg/day during summer phase. Weaning weights were also similar (P=.79) for all treatments and averaged 219 kg.

Wilting before harvesting and storing increased the DM content of an average bale from experiments 1 and 2 from 174 kg for unwilted silage to 238 kg (36.78%) for 1 to 2h-wilted and 295 kg (71.3%) for 2 to 4h-wilted silage. The increased output of forage DM per bale due to wilting may result in lower storage costs per unit of nutrients (kg TDN or kg CP) because of the reduction in plastic, labor and fuel costs. The CP concentrations of forages in experiment 1 were higher than that of forages used in experiment 2, but IVOMD for bermudagrass forages for both experiments were not different.

In experiment 1, the intake (% BW) of 1 to 2h-wilted and 2 to 4h-wilted silages and hay were 19%, 28% and 29% higher, respectively, than the intake of unwilted silage. In experiment 2, intake (% BW) of wilted silages and hay were only increased by 7%, 10% and 6%, respectively, compared to the intake of unwilted silage.

All cows lost weight during winter, but the unwilted groups lost consistently more weight averaging -0.63 kg/day for experiments 1 and 2. The hay groups lost less (-0.24 kg/day) in both experiments. Daily weight loss of cows fed wilted silages ranged from -0.20 kg to -0.50 kg and from -0.77 kg to -0.23 kg for 1 to 2h-wilted and 2 to 4h-wilted silages, respectively. Summer weight changes showed trends toward compensation: the unwilted and 2 to 4h-wilted silage groups which lost more weight in experiment 1 gained more weight during the summer phase. The same trend for compensation was found in experiment 2 with cows fed unwilted and 1 to 2h-wilted silages. In contrast, cows fed hay and 2 to 4h-wilted silage (with less weight loss during the winter) gained 0.01 kg/day.

Body condition score changes followed trends in winter and summer weight changes for both experiments 1 and 2. In experiment 2, calf gains averaged 0.69 kg/day during winter and 1.31 kg/day when grazing during the summer. Weight changes of cows may be related to use of nutrients mobilized for milk production. Pregnancy rates and calf weaning weights were also similar for all treatments in both experiments 1 and 2, suggesting some management flexibility for manipulating cow-calf production through winter feeding and summer pasture schemes.

General Discussion

One of the major concerns, nutritionally, of calving in the fall is that of matching the cow's requirements with the backbone of the nutritional resources. During winter, at the time of greatest nutritional needs for the herd, the producer is confronted with low forage availability (Hembry, 1991). Feeding harvested forages offers opportunities to improve the quantity and the quality of the forage available to feed cattle during the winter. Most cows in Forida are wintered on grass hay. Depending on the stage of growth, this hay will usually contain 7% to 8% CP and will be deficient in both protein and energy to meet the requirements of lactating cows and their calves.

The bermudagrass round bale forages fed to cows in these experiments were harvested at 8-weeks of regrowth. Changes in forage DM intake due to wilting may not explain entirely differences in animal performance. Cows lost weight during winter for all treatments. The high weight loss for the unwilted and 2 to 4h-wilted cows groups as compared to 1 to 2h-wilted silages and hay groups may be explained by factors other than feeding level. Cows were in negative energy balance and factors such as changes in gut fill or empty-body composition may have contributed to change in body weight.

Cow weight changes, pregnancy and calf weaning weights were similar across all treatments for both experiments. For both experiments, the body condition of cows at the beginning of winter ranged from 5.8 to 6.7. Body condition score loss ranged from -0.10 to -1.28. Kunkle et al. (1991) reported, under practical conditions in Florida, a pregnancy rate of 75% for a herd of average body condition score of 4.3. Feeding a less mature harvested forage may decrease condition score loss. This has important practical implications in systems of management in which beef cattle may be required to gain weight and body condition score throughout the annual cycle. The alternating use and replenishment of body reserves offers opportunities to economize in the use of supplements at certain stages of the cycle. The beef cow utilizes a greater proportion of her energy intake for maintenance energy requirements compared to the dairy cow, and about 70% of the energetic cost for beef cow production is attributable to maintaining the cow (Jenkins and Ferrell, 1983). Feeding round bale grass silage may allow feeding management based on the body condition score and liveweight change of suckled cows. This may result in improved pregnancy rate for the cow and improved weaning weight of calves.

CHAPTER V
EVALUATION OF ROUND BALE BERMUDAGRASS FORAGES AS WINTER FEED FOR GROWING CATTLE AND COWS.

Introduction

Supplementing beef cattle during winter in Florida is common but costly. Reducing winter feed cost requires supplementation practices that meet nutritional requirements of animals while enhancing forage utilization. Energy supplementation of animals consuming low quality forages often results in depressed cellulose and hemicellulose digestibility (Henning et al., 1980; Kartchner, 1981), reduced protein digestibility (Cook and Harris, 1968) and decreased intake of forages (Crabtree and Williams, 1971a, 1971b). In contrast, supplementing low quality forages with NPN or true protein frequently increased forage intake (Amos and Evans, 1976; Kartchner, 1981), improved CP digestibility (Coleman and Wyatt, 1982) and elevated fiber digestibility (Lyons et al., 1970). Conserved legumes or grasses harvested at an early stage of growth are generally less costly than traditional energy or protein supplements. The potential of feeding systems combining hay and silage as winter feed has not been fully exploited. In a study with alfalfa hay and silage at a 1:1 ratio (Smith, 1976), DM intakes and gains of growing cattle were similar to those achieved with higher quality hay diets. Miller et al. (1965) reported higher milk production, weight gain and forage consumption for lactating cows with limited grazing and grass silage fed ad libitum than cows fed grass-legume silage ad libitum or grazing a ryegrass pasture.

In North Florida, many beef cows are wintered on grass hay having 7 to 8% CP which is adequate for maintaining pregnant cows through the winter. Most hays are deficient, however, in both CP and energy for lactating and growing cattle. Supplement is required to prevent decreased productivity of the beef cow, and this will result in higher feed costs. Round bale silage systems offer some potential for improving winter forage quantity and quality. Hay and wilted silage are weather dependent, and under practical conditions a system combining unwilted grass silage, wilted grass silage and hay may be more reliable than a single forage system.

This study was conducted to determine if feeding early cut bermudagrass as wilted round bale silages or round bale hay to growing cattle and beef cows would reduce winter feed costs. Differences in intake and nutrient concentrations of forages reported in chapters 3 and 4 determined the levels of supplements required to balance diets.

In this analysis, a linear program was used to determine least cost balanced diets for wintering growing cattle and lactating cows fed bermudagrass forages supplemented with sources of energy and protein.

Materials and Methods

Linear programming involves selection of a set of decision variables that minimize (or maximize) a linear objective function (i.e., feed cost per cow per day) subject to a series of linear restrictions (i.e., maximum

DM intake, minimum ME per day required, etc.) and the requirement that the decision variables cannot be negative (i.e., there cannot be negative amounts of feed per cow per day). Mathematically the feed ration problem can be written as

$$Min\ Z = \sum_{j=1}^{n} c_j X_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad (i = 1...m)$$

and

$$x_j \geq 0 \ (j = 1, .., n)$$

where n=number of feeds available, c_j = cost/kg of DM for the j^{th} feed, x_j. The b_i are daily requirements (i.e., ME, Mcal/cow/day) for the specified performance rate, a_{ij} is the quantity of the i_{th} nutrient per kg of the j_{th} feed (i.e., ME/kg unwilted silage). The elements of the vector (X_1, X_2, ..., X_n) are called the activities.

Nutrient Requirements of Animals

The nutrient requirements of animals are given in Table 5.1. The daily feed requirements for a lactating cow and a heifer were calculated by balancing rations for: maximum DM intake and minimum ME and CP. The cow was assumed to weigh 500 kg and to produce 5 kg milk/day. Least cost rations were determined at 100% and 85% of cow requirements. The heifer weighed 240 kg and was assumed to gain 0.6 kg per day.

Table 5.1. Animal Requirements.

		Cow[b]	
Nutrients	Heifer[a]	100%[c]	85%[c]
Maximum DM intake, kg/day	5.94	9.90	9.90
Minimum ME, Mcal/day	12.1	20.3	17.3
Minimum CP, g/day	538	957	813

[a] Heifer (240 kg liveweight) gaining 0.6 kg per day; NRC, 1984.
[b] Cow (500 kg liveweight) maintaining bodyweight and producing 5 kg milk per day; NRC, 1984.
[c] Cow fed at 100% and 85% of requirements.

Nutrient Concentrations of Feeds

Nutrient recovery at harvesting, storage and feeding determined the net output of nutrients available for animals. Forage losses during harvesting, storing, feeding and the associated costs of production and storage for unwilted silage, wilted silage and hay are given in Table 5.2 and 5.3. The DM consumed, as % of DM harvested, ranged from 75.97% for the 2 to 4h-wilted silages to 77.26, 78.71 and 84.97% respectively for 1 to 2h-wilted silage, unwilted silages and hay, respectively. Storage losses and feeding losses were higher for round bale silages as compared to hay.

Nutrient concentrations of forages and concentrates are shown in Tables 5.4. The DE of forages was converted to ME by multiplying by 0.82 (NRC, 1984). Blackstrap molasses and cottonseed meal (CSM) were used as energy and protein supplements to balance diets of growing cattle. Molasses-urea was used to supplement cow diets.

The Structure of the Model

Individual activities allow for the total consumption of a given forage and the use of the supplement to meet animal requirements without exceeding the voluntary DM consumption of the animal. For example, to meet requirements a cow must exhaust the intake potential of each forage before using molasses-urea.

Four equations were used to control the nutritional requirements of the cow and growing heifer. For each animal, three equations limit daily DM intake, ensure a minimum amount of ME and ensure that a minimum CP requirement are met. An equation ensures that the intake potential of a

Table 5.2. Recovery of Round Bale Bermudagrass Forages from Cutting to Consumption.

Item	Wilting time			Hay[a]	Mature Hay[b]
	None[a]	1 to 2h[a]	2 to 4h[a]		
Forage DM, %					
Harvest	28.6	37.7	50.3	81.5	81.5
Feeding	26.1	35.4	47.6	87.4	87.4
Forage yield					
MT DM/ha cut	9.9	9.9	9.9	9.9	9.9
Bale DM, kg	189	245	282	257	257
Harvesting losses, %DM[c]	2	3	5	10	10
DM loss, MT/ha	0.20	0.30	0.50	0.99	0.99
Harvested yield, MT/ha	9.70	9.60	9.41	8.91	8.91
Bales/ha at harvest	51.33	39.20	33.35	34.67	34.67
Storage losses, %DM	12.45	11.50	8.75	2.95	2.95
Storage loss, MT/ha	1.21	1.10	0.82	0.26	0.26
Fed yield, MT/ha	8.49	8.50	8.58	8.65	8.65
Feeding losses, %DM	10.10	12.70	16.75	12.45	12.45
Feeding loss, MT/ha	0.86	1.08	1.44	1.08	1.08
DM consumed, MT/ha	7.64	7.42	7.14	7.57	7.57
DM consumed, % DM harvested	78.71	77.26	75.97	84.97	84.97
Total losses					
%DM harvested	21.29	22.74	24.03	15.03	15.03
%DM at cutting	22.87	25.06	27.83	23.53	23.53

[a] 5week regrowth interval, 4 cuts/year

[b] 8-10 week regrowth interval, 2 cuts/year.

[c] Based on literature review and consultation with agronomists.

Table 5.3. Costs of Production of Round Bale Bermudagrass Forages[a]

	Wilting time[a]				
Item	None[b]	1 to 2h[b]	2 to 4h[b]	Hay[b]	Mature Hay[c]
Bales consumed/ha	51.33	39.20	33.35	34.67	34.67
Production costs					
$/ha	291.60	291.60	291.60	291.60	172.60
$/MT DM harvested	30.06	30.37	31.00	32.73	19.37
$/bale harvested	5.68	7.44	8.74	8.41	4.98
Harvesting cost					
Mow/raking[d]					
$/ha	100.00	100.00	100.00	100.00	50.00
$/MT DM harvested	10.31	10.41	10.63	11.22	5.61
$/bale harvested	1.95	2.55	3.00	2.88	1.44
Baling cost, $/bale					
$/ha	308.00	308.00	308.00	308.00	308.00
$/MT DM harvested	31.75	24.49	21.28	23.35	23.35
$/bale harvested[e]	6.00	6.00	6.00	6.00	6.00
Storage cost					
$/ha	328.53	250.85	213.45	0.00	0.00
$/MT DM harvested	33.86	26.12	22.70	0.00	0.00
$/bale harvested[f]	6.40	6.40	6.40	0.00	0.00
Total cost[g]					
$/ha	1,028.13	877.63	805.15	599.62	430.2
$/MT DM harvested	105.97	91.39	85.61	67.30	48.33
$/bale harvested	20.03	22.39	24.14	17.30	12.42
$/MT consumed					
Dry matter[h]	134.64	118.29	112.69	79.20	56.88
As fed	35.14	41.87	53.64	69.22	49.71

[a], [b], [c] same as in Table 5.2. [d] Custom rates. $25.00/ha for 4 cuts or 2 cuts, Hewitt, 1987. [e] Custom rates $6.00/bale adjusted for small bales from Hewitt, 1987. [f] From Kunkle et al., 1988. [g] Feeding costs not included. [h] $/ton adjusted for DM losses during storage and feeding.

Table 5.4. Nutrient Concentrations and Costs of Forages and Concentrates

Feed	Dry matter,%	Crude protein, % DM	ME, Mcal/kg DM	Cost, $/kg as fed	Cost, $/kg DM
Unwilted silage	26.1	14.0	1.97	0.035[a]	0.135
1 to 2h-wilt	35.4	14.1	1.89	0.042[a]	0.118
2 to 4h-wilt	47.6	13.9	1.87	0.054[a]	0.113
Hay	87.4	13.5	1.81	0.069[a]	0.079
Mature hay	87.4	7.0	1.60	0.050[b]	0.057
Blackstrap molasses	78.0	5.8	2.86	0.113[b]	0.145
Molasses-urea	75.0	16.0	2.37	0.154[b]	0.205
Cottonseed meal	93.0	44.3	2.82	0.284[b]	0.305

[a] From Table 5.3, as fed.

[b] Market prices; summer 1991.

harvested forage is fully exploited before using supplements. The average forage DM intake as % BW for growing cattle (Chapter 3) and cows (Chapter 4) was used to compute the intake potential for each forage. Livestock nutritional requirements were balanced within the limits of forage intake. An equation was used to cause a 50% or 25% depression in ME intake of forages when supplemental concentrates were used (Moore et al., 1991). To illustrate, the model for the unwilted silage is as follows:

$0.135x1 + 0.145x3 + 0.305x4 = \min$ \$/day.

subject to

$x1 + x3 + x4 <= 5.94$, maximum kg DM/day.

$1.97x1 + 2.60x3 + 2.82x4 >= 12.10$ Mcal/day, minimum ME required.

$140x1 + 58x3 + 443x4 >= 538.4$ g/day, minimum CP required.

$x1 + x2 = 4.0$ kg DM/day, maximum DM intake of unwilted silage.

$1.97x2 - 1.43x3 - 1.41x4 = 0$, ME depression factor (50%).

where

$x1$ = unwilted silage fed,

$x2$ = unwilted silage not fed,

$x3$ = molasses

$x4$ = cottonseed meal.

Results and Discussion

Nutrient Specifications and Nutrient Contents of Rations

Animal nutrient requirements and nutrient contents of diets are given in Table 5.5 for heifers and Table 5.6 for mature lactating cows.

Table 5.5. Nutrient Specifications and Nutrient Contents of Diets. Growing Cattle Experiments

Item	NRC levels	Diet nutrient contents[a]				
		I	II	III	IV	V
1. SR = 50%[b]						
DM intake, kg/day	5.94	4.81	5.00	5.11	4.90	4.26
ME, Mcal/day	12.1	12.1	12.1	12.1	12.1	12.1
Protein, g/day	538	539	538	538	540	540
2. SR = 25%[b]						
DM intake, kg/day	5.94	5.24	5.47	5.56	5.48	5.34
ME, Mcal/day	12.1	12.1	12.1	12.1	12.1	12.1
Protein, g/day	538	572	620	637	578	536

[a] Diets. I = unwilted silage, II = 1 to 2h-wilted silage
III = 2 to 4h-wilted silage, IV = Early cut hay
V = Late cut hay (48% TDN and 7% CP).

[b] SR = Substitution rate.

Table 5.6. Nutrient Specifications and Nutrient Contents of Diets. Cow Experiments

Item	NRC levels	Diet nutrient contents[a] I	II	III	IV	V
1. Cow fed at 100% of Requirements						
a. SR = 50%						
DM intake, kg/day	9.90	9.32	9.75	9.90	9.90	8.97
ME, Mcal/day	20.3	20.3	20.3	20.3	20.3	20.3
Protein, g/day	957	1401	1449	1457	1432	1321
b. SR = 25%						
DM intake, kg/day	9.90	9.65	9.90	9.90	9.90	9.40
ME, Mcal/day	20.3	20.3	20.3	20.3	20.3	20.3
Protein, g/day	957	1415	1440	1424	1380	1273
2. Cow fed at 85% of requirements						
a. SR = 50%						
DM intake, kg/day	9.90	9.90	9.90	9.90	9.90	9.90
ME, Mcal/day	17.3	17.3	17.3	17.3	17.3	17.3
Protein, g/day	813	1207	1264	1274	1254	1016
a. SR = 25%						
DM intake, kg/day	9.90	8.46	8.90	9.05	9.21	9.14
ME, Mcal/day	17.3	17.3	17.3	17.3	17.3	17.3
Protein, g/day	813	1214	1271	1280	1261	945

[a] Diets. I = unwilted silage, II = 1 to 2h-wilted silage III = 2 to 4h-wilted silage, IV = Early cut hay V = Late cut hay (48% TDN and 7% CP).

Rations were balanced with regards to energy and protein concentrations of forages and the animal consumption capacity for each forage.

For growing cattle, DM intakes of diets were below NRC DM levels for all rations at sustitution rates (SR) of 50% and 25%. At the SR of 25%, more DM was consumed than at SR of 50%. The diets provided sufficient ME and CP to meet NRC requirements.

Dry matter intake was below or equal to NRC DM levels in the model for lactating cows fed at 100% and 85% of cow requirements. The ME and CP concentrations of the diets met or exceeded NRC levels.

Costs of Balanced Rations

Winter feed costs are given in Table 5.7 for growing cattle and Tables 5.8 and 5.9 for mature lactating cows. Both heifers and cows were fed for a winter feeding period of 120 days.

Blackstrap molasses was fed to heifers ad libitum. At the SR of 50%, the cost of wintering a heifer on early cut hay was $76.96. It cost $3.97 and $5.53 more, respectively, to feed a heifer during winter using 2 to 4h-wilted or 1 to 2h-wilted silage rations compared to early cut hay rations. Unwilted silage or late cut hay rations were less competitive than hay or wilted silage rations. The cost of wintering a heifer on the unwilted silage ration was $9.88 more per heifer than that of early cut hay. Unwilted silage was less expensive as winter feed than late cut hay which cost $11.33 more per heifer than early cut hay. At the SR of 50%, the proportion of supplements in the balanced rations for growing heifers ranged from 50.49% for 2 to 4h-wilted silages to 99.06% for late cut hay. The proportion of supplements for 1 to 2h-wilted silages (54.40%) is less

Table 5.7. Least Cost Diets at Ad Libitum Feeding of Supplements. Growing Cattle Experiments

Rations	Feed	Amount, kg DM	Cost, $/day	Total cost, $/heifer/year
1. SR = 50%				
I	Unwilted silage	1.86		
	Molasses suppl.	2.67		
	Cottonseed meal	0.28	0.72	86.84
II	1 to 2h silage	2.28		
	Molasses suppl.	2.57		
	Cottonseed meal	0.15	0.69	82.49
III	2 to 4h silage	2.53		
	Molasses suppl.	2.49		
	Cottonseed meal	0.09	0.67	80.93
IV	Hay	1.80		
	Molasses suppl.	2.79		
	Cottonseed meal	0.31	0.64	76.96
V	Mature hay	0.04		
	Molasses suppl.	3.46		
	Cottonseed meal	0.76	0.74	88.29
2. SR = 25%				
I	Unwilted silage	3.27		
	Molasses suppl.	1.97	0.73	87.25
II	1 to 2h silage	3.65		
	Molasses suppl.	1.82	0.69	83.25
III	2 to 4h silage	3.84		
	Molasses suppl.	1.72	0.68	82.00
IV	Hay	3.42		
	Molasses suppl.	2.06	0.57	68.27
V	Mature hay	2.53		
	Molasses suppl.	2.30	0.63	75.99

Table 5.8. Least Cost Diets at 100% of Cow Requirements. Cow Experiments.

Rations	Feed	Amount, kg DM	Cost, $/day	Total cost, $/cow/year
1. SR = 50%				
I	Unwilted silage	4.47		
	Molasses-urea	4.85	1.59	191.72
II	1 to 2h silage	5.84		
	Molasses-urea	3.91	1.49	178.88
III	2 to 4h silage	6.32		
	Molasses-urea	3.58	1.45	173.77
IV	Hay	5.81		
	Molasses-urea	4.09	1.29	155.69
V	Mature hay	1.26		
	Molasses-urea	7.71	1.65	198.28
2. SR = 25%				
I	Unwilted silage	6.44		
	Molasses-urea	3.21	1.52	183.29
II	1 to 2h silage	7.57		
	Molasses-urea	2.33	1.37	164.51
III	2 to 4h silage	8.00		
	Molasses-urea	1.90	1.29	155.22
IV	Hay	7.82		
	Molasses-urea	2.07	1.04	125.23
V	Mature hay	2.56		
	Molasses-urea	6.84	1.54	185.77

Table 5.9. Least Cost Diets at 85% of Cow Requirements. Cow Experiments.

Rations	Feed	Amount, kg DM	Cost, $/day	Total cost, $/cow/year
1. SR = 50%				
I	Unwilted silage	6.03		
	Molasses-urea	2.27	1.27	153.53
II	1 to 2h silage	7.46		
	Molasses-urea	1.33	1.15	138.35
III	2 to 4h silage	7.96		
	Molasses-urea	1.00	1.10	132.54
IV	Hay	7.46		
	Molasses-urea	1.59	0.91	109.83
V	Mature hay	3.37		
	Molasses-urea	4.88	1.19	143.10
2. SR = 25%				
I	Unwilted silage	6.95		
	Molasses-urea	1.51	1.24	149.74
II	1 to 2h silage	8.02		
	Molasses-urea	0.88	1.12	135.21
III	2 to 4h silage	8.39		
	Molasses-urea	0.66	1.08	130.00
IV	Hay	8.16		
	Molasses-urea	1.05	0.85	103.19
V	Mature hay	5.74		
	Molasses-urea	3.40	1.02	122.90

than that required for early cut hay (63.27%) and unwilted silages (61.33%). The high cost of the unwilted silage diet is due not only to the high level of supplement required to balance this diet, but also to the high initial cost of the forage. The early cut hay required 1.94% more supplement than the unwilted silage, but its cost is lower than unwilted silage.

The proportion of CSM in the ration also varied among forages and this contributed to cost differences between rations. CSM was 6.3% of the early cut hay ration and 5.8%, 3.0% and 1.2% of unwilted, 1 to 2h-wilted and 2 to 4h-wilted rations, respectively.

At the SR of 25%, early cut hay diets had a lower cost than silage diets, similar to the observation with a 50% SR. The mature hay ration cost $11.26, $7.26, and $6.01 less per heifer than unwilted, 1 to 2h-wilted and 2 to 4h-wilted diets, respectively. The level of concentrates in the rations ranged from 30.94% for the 2 to 4h-wilted silage to 33.27%, 37.60%, 37.59% and 52.62% for 1 to 2h-wilted silage, unwilted silage, early hay and mature hay, respectively.

Wintering costs of lactating cows on early cut hay ($155.69/cow at 100% feeding level) were lower at 100% and 85% of cow requirements than other forage rations. At 100% of cow requirements, costs for a cow wintered on 2 to 4h-wilted, 1 to 2h-wilted and unwilted silages at the SR of 50% were $173.77, $178.88 and $191.72, respectively. The late cut hay ration cost $6.56 more per cow than the unwilted silage ration. For these rations at the SR of 25%, costs of wintering cows were $155.22, $164.51 and $183.29 for 2 to 4h-wilted silage, 1 to 2h-wilted silage and unwilted silage, respectively. The early cut hay ration was $29.99 cheaper than the 2 to 4h-wilted silage ration, which in turn was $30.55 cheaper than the mature hay ration. The levels of supplement required to balance the rations containing unwilted silage (52.04%) and late cut hay (85.95%) were higher than the levels of supplement required to balance the rations containing 1 to 2h-wilted silage, 2 to 4h-wilted silage and early cut hay (40.10%, 36.16% and 41.31%, respectively). A high level of supplement in a diet resulted in higher winter feed costs. Differences in feed costs, however, between early cut hay and wilted silage rations were not due to differences in the proportion of supplements. The early cut hay ration required 5.15% and 1.21% more supplement than the 2 to 4h-wilted and 1 to 2h-wilted silages, but the cost of the early cut hay ration was lower than the cost of the latter forages. The lower cost of producing the early cut hay explained the cost differences in the cost of the ration containing it as compared to the silages.

When the cow was fed at 85% of requirements and at the SR of 50%, winter feed costs per cow decreased from $153.53 for unwilted silages to $138.35, $132.54 and $109.83 for 1 to 2h-wilted silage, 2 to 4h-wilted silage and early cut hay, respectively. At 85% of cow requirements, the major change in rations was an increased proportion of forages and the consequent reduction in the levels of supplements required to balance the rations. Supplements represented 27.35% of the unwilted silage ration and 15.13%, 11.16%, 17.57% and 59.15% of 1 to 2h-wilted silage, 2 to 4h-wilted silage, early cut hay and late cut hay rations, respectively. The higher proportion of forages in these rations resulted in low winter feed costs per cow compared to maintenance or 85% requirements. Winter feed cost per cow for an early cut hay ration was $109.83. It cost $22.71 more per cow when the 2 to 4h-wilted silage was fed, and \$28.52, \$43.70 and \$33.27 more per cow for 1 to 2h-wilted, unwilted and late cut hay compared to feeding early cut hay. The 25% SR resulted in higher levels of forages in the diets of cows fed at 100% and 85% of requirements. This also resulted in low winter feed costs for cows.

General Discussion

Many factors are involved in the decision making concerning choice of a winter feeding system. Total forage production, recovery of harvested forage at consumption and the nutrient concentrations for each forage determine winter feed costs for growing heifers and lactating cows.

This study showed a lower recovery of DM from harvesting to consumption for round bale bermudagrass silages than round bale hay. Storage losses were particularly higher for silages than hay. Unwilted silage had lower feeding losses than 1 to 2h-wilted and 2 to 4h-wilted silages as well as hay. Higher feeding losses were observed for 2 to 4h-wilted silages in the second experiment. Reasons for these losses are not known. Molding and suboptimal fermentation related to plastic deterioration may affect forage palatability resulting in higher levels of wasteage. The least cost forage system for wintering both growing cattle and mature lactating cows was the early cut hay. The cost of forages including production, harvesting, storing and feeding and the costs of supplements required to balance diets determined the total winter costs. Improving the quality of forages would lower the winter cost for these categories of animals.

Winter energy requirements for fall calving beef cows are influenced by cow size, breed (Klosterman et al., 1968; Lemenager et al., 1980), environment (Young and Dietz., 1971) and body condition (Klosterman et al., 1968; Kunkle et al., 1991). Under practical conditions, feeding management can be designed to establish optimum body condition during appropriate periods of the year, but the type of feeding management will depend on climate and animal characteristics. Fat cows at calving may be allowed to use body stores during early lactation by feeding them below requirements. Thin cows may be fed to maintain or increase body condition during lactation. In this study, cows were fed at 100% and 85% of cow requirements to simulate different feeding managements.

The early cut hay was the most competitive alternative as a winter feed for mature lactating cows fed at 100% or 85% of cow requirements. Rations were formulated giving maximum dependance on forage. With silage rations, as the proportion of forage in the ration increased, the winter feed cost per cow decreased. When molasses-urea supplementation resulted in a 50% depression in the intake of forage ME (SR=50%; for a 500 kg cow producing 5 kg milk and maintaining her body weight), 6.32 kg DM of 2 to 4h-wilted silage and 3.58 kg DM of molasses supplement were required to provide 20.3 Mcal of ME and 957 g or more of protein. The cost of this ration was $173.77 per cow for a winter feeding period of 120 days. Using unwilted silage, 4.47 kg DM of unwilted silage and 4.85 kg DM of molasses-urea were required to meet the requirements of the same cow. It cost $17.95 more to winter a cow using unwilted silages than 2 to 4h-wilted silage. With the late cut hay, 1.26 kg DM of forage and 7.71 kg DM of molasses-urea were required to meet energy and protein requirements.

Additional cost for the late cut hay ration was $24.51 per cow compared to the 2 to 4h-wilted silage rations. When molasses-urea supplementation resulted in a 25% depression in ME in the intake of forages (SR=25%), the supplemented mature hay cost $30.55 more to maintain a cow during winter than 2 to 4h-wilted silages and $21.26 more than using 1 to 2h-wilted silage.

The early cut hay diet was the most competitive winter feed of all forages. The practical value of these feeding managements will depend, however, on the trade-offs between feed cost reduction, decreased calf crop, supplement cost and cost of storing the forage. This study showed that cost efficient winter diets were early cut hay and 2 to 4h-wilted silage for both growing and mature lactating cattle. The early cut hay and 2 to 4h-wilted silage rations required relatively less supplement than unwilted silage, 1 to 2h-wilted silage and late cut hay rations. The competitive advantage of the early cut hay may be explained by the lower cost of producing and storing hay as compared to silage. Early cut hay required more supplement than 2 to 4h-wilted silage, and at higher supplement costs, the competitive advantage of early cut hay as compared to 2 to 4h-wilted silage will decrease. Early cut hay stored outside may have a lower DM recovery than the DM recovery for early cut hay stored inside, and this would also decrease the competitive advantage of early cut hay. Technological alternatives to reduce forage losses (additives, appropriate polyethylene film) with 2 to 4h-wilted silage systems may decrease storage and feeding losses which will decrease the winter feed cost of this diet. Overall the round bale silage systems offer some flexibility for reducing the cost of winter feeding for cattle. An early cut hay system had a lower cost than silage systems, but the high risk of rainy weather may override its competitive advantage in subtropical environments.

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS FOR FUTURE RESEARCH

The following conclusions can be drawn from this study:

-Wilting and storing bermudagrass as wrapped round bale silage improved DM recovery of forages during storage.

-As bermudagrass is wilted from 2h to 4h, more DM was harvested and stored per bale. Harvested forage DM recovery at consumption was higher for the round bale hay system than silage systems.

-The DM intake of 2 to 4h-wilted silages (expressed as % of BW) was higher than that of unwilted silages, and the increased forage DM intake was reflected in higher liveweight gain of growing cattle.

-Wilting improved the digestibility of forage DM and OM, but did not improve the digestibility of GE or CP.

-Nitrogen retention by sheep fed unwilted silages was lower than that by sheep fed hay or 2 to 4h-wilted silage.

-Estimated forage DM intake of round bale bermudagrass forages fed to fall calving cows tended to be higher for wilted silages than unwilted silages.

-Cows fed round bale bermudagrass forages lost weight and body condition during winter, but tended to compensate equally over the combined winter and summer periods.

-Pregnancy rate and calf weaning weight were similar for all treatments.

-The early cut hay diet was the most competitive winter feed for both growing heifers and mature cows.

-Late cut hay at the 50% SR was the most costly winter diet because of the high levels of supplements required to balance the diet.

Future research could focus on

-Management systems to reduce storage and feeding losses with the round bale silage systems.

-The least cost balanced diets from chapter V may not be optimal under all feeding conditions (i.e., those with higher supplement costs, technological improvements, etc.) and these diets may require validation.

-Feeding management systems which combine different round bale bermudagrass forages may improve the biological and economic efficiency of the utilization of bermudagrass.

-Interactions between forage growth, yield at harvest and nutrient quantity and quality under different fertilization and cutting regimes, climatic conditions and energetic or economic efficencies deserve attention.

APPENDIX

DATA AND ANALYSIS OF VARIANCE TABLES

Data Codes

-OBS = Observation.

-TRT = Treatment. DC= Direct cut. 40 = Wilted for 1-2 hours.
50 = Wilted for 2-4 hours. Hay = Field cured hay
SSIL = Forage sorghum silage.

-HBWT = Bale weight at harvest (in pounds).

-FBWT = Bale weight at feeding (in pounds).

-HBDWT = Harvest dry weight of bale (in pounds).

-FBDWT = Feeding dry weight of bale (in pounds).

-HGE = Gross energy content of bale at harvest (kcal/g DM).

-FGE = Gross energy content of bale at feeding (kcal/g DM).

-HPDM = Percent dry matter of forage at harvest.

-FPDM = Percent dry matter of forage at feeding.

-HPOM = Percent organic matter of bale at harvest, % DM.

-HPCP = Percent crude protein of bale at harvest, % DM.

-FFWT = Forage weight at feeding, pounds.

-WTBK = Weightback, pounds.

-WAST = Wasteage, pounds.

-DMNCN = Dry matter non consumed, pounds.

-DMFED = Dry matter fed, pounds.

-DML = Dry matter loss, % forage fed.

-DMCON = Dry matter consumed, pounds.

-NAN = Number of animals.

-DYBL = Days per bale.

-TFDY = Total feed days.

-DDMIN = Daily dry matter intake, kg.

Data Codes "continued"

-AFWT = Average full weight of cows, pounds.

-FPCP = Percent crude protein of forage, % DM.

-IVOMD = In vitro organic matter digestibility (%).

-FPOM = Percent organic matter of bale at feeding, %DM.

-FPNDF = Percent neutral fiber of bale at feeding, %DM.

-PK1 = Peak height ammonia replicate 1.

-PK2 = Peak height ammonia replicate 2.

-AC1 = Acetic acid replicate 1, as % total DM.

-AC2 = Acetic acid replicate 2, as % total DM.

-AMM1 = Ammonia nitrogen replicate 1, as % total N.

-AMM2 = Ammonia nitrogen replicate 2, as % total N.

-BUT1 = Butyric acid replicate 1,. as % total DM.

-BUT2 = Butyric acid replicate 2, as % total DM.

-LAC1 = Lactic acid replicate 1, as % total DM.

-LAC2 = Lactic acid replicate 2, as % total DM.

-SW1 = Shrunk weight beginning trial, pounds.

-SW2 = Shrunk weight end trial, pounds.

-HDAY = Head days.

-DFOF = Daily forage offered, pounds.

-DMOF = Dry matter offered, pounds.

-FCON = Forage consumed, pounds.

-DMCN = Dry matter consumed, pounds.

-DML = Dry matter lost, % DM fed.

-GE = Gross energy content (kcal/g DM).

-PGED = Gross energy digestibility (%).

Data Codes "continued"

-FW1 = Full weight beginning trial, pounds.

-PS1 = Percent shrunk beginning trial.

-FW2-FW6 = Full weight period 1...period 6, pounds.

-DFILL = Difference fill, pounds.

-WADF = Adjusted weight for fill, pounds.

-KCS1, KCS2, BCS1, BCS2, body condition score observers 1 and 2, respectively.

-WCHP1, WCHP2, WCHP3= weight change period 0-1 1-2,2-3, (pounds).

-WCG1, WCG2, WCG3 = weight change period 0-2, 0-3, 0-4.

-SWCG= Shrunk weight change.

-AHCG = Average height change, in cm.

-AFED = Forage fed, kg for 7 days.

-ORT= Amount ort, kg for 7 days.

-FCS = Amount feces, kg for 7 days.

-FDM = Forage %DM.

-ODM = Ort %DM.

-FSDM = Feces %DM.

-FOM = Forage %OM.

-OOM = Ort %OM.

-FSOM = Feces %OM.

-OGE = Ort GE.

-FCP = Forage %CP.

-FGE = Forage GE.

-FSGE = Feces GE.

Data Codes "continued"

-OCP = Ort %CP.

-FSCP = Feces %CP.

-ONDF = Ort %NDF.

-CPINT = Crude protein intake, gm.

-AMUN = Weight of urine, gm.

-DMAG = Age of dam, years.

-CW1..CWT6 = Cow weight period date 1 to date 6, pounds.

-FNDF = Forage %NDF.

-FCON = Weight of forage consumed.

-FSNDF = Feces %NDF.

-CPFCS = CP feces, gm

-PCPUN = Urine %CP.

-Pen = Pen.

-PRE = Pregnancy status.

Table A.1. Nutrient Recovery. Growing Cattle Experiment 1

OBS	TRT	HBWT	FBWT	HBDWT	FBDWT	HGE	FGE	HPDM	FPDM
1	DC	1410	1180	335.8	286.9	3785.9	4416.9	22.68	24.34
2	DC	1360	1230	427.5	311.6	4408.1	4854.2	24.73	23.47
3	DC	1210	1150	329.9	282.1	4881.4	4935.1	23.20	23.73
4	DC	1180	1180	314.5	292.5	4478.6	4573.5	20.57	25.82
5	DC	1300	1177	367.3	282.6	4932.7	5272.3	25.13	21.42
6	DC	1350	1190	299.7	259.7	4718.0	5456.7	28.01	22.53
7	DC	1320	1150	359.6	283.6	4155.3	5045.7	24.10	23.42
8	DC	1290	1223	330.0	290.8	4432.3	4719.3	21.31	26.16
9	DC	1180	1180	332.8	287.9	4187.0	4557.6	26.35	25.09
10	DC	1370	1240	366.2	309.5	4666.3	4698.8	30.47	21.52
11	DC	1640	1520	458.4	414.1	4542.4	4843.8	25.29	24.18
12	DC	1320	1120	251.0	236.8	4375.3	4245.0	24.48	18.96
13	HAY	520	505	512.1	443.0	3767.8	4097.5	98.49	87.72
14	HAY	640	620	540.7	549.6	4161.4	4043.1	84.49	88.65
15	HAY	670	660	586.1	587.7	4017.5	4055.3	87.47	89.05
16	HAY	630	600	554.6	557.4	3989.9	4218.8	88.03	88.48
17	HAY	540	505	480.4	445.8	3992.1	3109.5	88.96	88.28
18	HAY	660	630	576.6	559.1	4035.7	4267.7	87.37	88.75
19	HAY	650	640	560.9	573.2	4322.2	4198.9	86.29	89.56
20	HAY	670	640	599.5	558.4	4253.1	4190.5	89.47	87.25
21	HAY	670	630	574.1	548.3	4005.9	4211.1	85.69	87.03
22	HAY	650	630	531.2	540.7	4317.9	4318.6	82.73	85.83
23	HAY	560	545	492.8	477.4	3980.6	4177.1	88.00	87.60
24	HAY	560	545	505.8	485.5	3940.8	4184.0	90.32	89.09
25	40	1270	1270	491.5	404.8	4979.9	4633.0	34.84	29.16
26	40	1420	1420	506.2	413.1	3951.2	4349.5	38.30	36.32
27	40	1340	1310	501.8	387.9	4481.3	4110.5	41.50	25.85
28	40	1330	1330	410.5	422.7	4653.1	4615.0	31.18	33.07
29	40	1380	1300	517.5	474.1	3885.8	4312.0	40.89	32.67
30	40	1470	1420	595.8	522.6	3972.8	4398.8	45.13	34.33
31	40	1280	1190	439.7	364.7	4910.7	4681.6	36.08	27.35
32	40	1290	1290	476.9	367.8	3760.6	4097.3	31.12	28.42
33	40	1240	1210	474.6	369.7	4471.2	4447.4	39.34	33.67
34	40	1360	1330	498.8	490.1	4859.5	4641.8	34.42	33.25
35	40	1320	1320	528.9	479.9	4669.8	4787.4	30.47	32.41
36	40	1330	1330	521.9	471.9	4369.9	4594.9	26.87	33.21
37	50	1190	1150	509.6	465.9	4585.9	4250.8	43.48	42.34
38	50	1380	1340	703.8	650.3	4611.2	4358.2	50.84	39.70
39	50	1730	1710	856.7	792.1	4658.8	4679.5	42.80	44.27
40	50	1080	1070	516.9	495.1	4383.9	4404.7	40.72	44.79
41	50	1350	1250	616.1	512.1	4192.4	4787.0	42.69	39.74
42	50	1330	1180	629.2	537.9	4655.5	4516.1	38.84	42.62
43	50	1220	1130	595.8	537.5	4224.1	4593.4	42.80	40.43
44	50	1470	1365	616.0	605.9	4597.2	4537.3	35.51	39.78
44	50	1370	1270	679.6	637.7	4867.5	4161.9	48.17	36.25
45	50	1240	1160	559.5	498.5	4843.3	4233.5	33.75	45.88
46	50	1270	1130	607.7	526.2	4305.0	4371.9	37.96	45.64
47	50	1130	1090	601.3	528.5	4636.5	4973.2	36.56	38.16

Table A.2. Analysis of Variance of Dry Matter and Gross Energy Recovery at Feeding. Growing Cattle Experiment 1

Recovery, %	Source	df	Sum of Squares[a]	P
Dry matter				
	Trt	3	991.2	0.0001
	Error	44	1667	
Gross energy				
	Trt	3	612.9	0.0452
	Error	44	370	

[a] Type III sum of squares

Table A.3. Nutrient Recovery. Growing Cattle Experiment 2

OBS	TRT	HBWT	FBWT	HPDM	FPDM	HBDWT	FBDWT	HGE	FGE
1	DC	1700	1610	28.99	27.80	492.9	447.5	4335	4867
2	DC	1620	1530	29.41	26.55	476.5	406.2	4072	4591
3	DC	1400	1370	34.29	30.87	479.9	422.9	4452	4332
4	DC	1510	1490	30.90	26.84	466.5	399.8	4025	4587
5	DC	1550	1620	31.77	30.56	492.5	495.1	4299	4459
6	DC	1390	1370	34.04	32.33	473.2	442.9	4459	4514
7	DC	1610	1540	28.78	24.16	463.4	372.1	4241	4885
8	DC	1700	1600	32.54	26.66	553.2	426.6	4246	4353
9	DC	1480	1420	29.91	27.44	442.7	389.7	4053	4570
10	DC	1420	1390	29.89	29.05	424.4	403.8	4833	4747
11	DC	1500	1470	28.49	27.71	427.3	407.4	4505	4531
12	DC	1530	1530	34.67	31.12	530.4	476.2	4299	4590
13	DC	1440	1430	39.47	36.04	568.4	515.4	4689	5138
14	40	1550	1430	35.04	31.68	543.1	453.0	4753	4304
15	40	1380	1340	37.25	34.48	514.1	462.0	4709	4690
16	40	1430	1390	33.32	29.21	476.5	406.1	4325	4658
17	40	1410	1410	38.74	36.16	546.3	531.6	4605	4223
18	40	1460	1440	43.74	39.79	638.6	572.9	4484	4814
19	40	1480	1320	35.16	38.31	520.4	505.6	4743	4564
20	40	1450	1390	38.39	36.63	556.7	509.2	4597	4713
21	40	1460	1460	37.12	32.03	541.9	467.7	4491	4536
22	40	1530	1320	38.47	36.67	588.6	484.0	4562	4886
23	40	1300	1260	45.38	43.40	589.9	546.8	4596	4794
24	40	1500	1500	42.15	41.14	632.3	617.1	4645	4199
25	50	1630	1550	33.17	32.71	540.7	506.9	4342	4426
26	50	1350	1330	45.83	43.18	618.7	574.3	4658	4674
27	50	1460	1440	44.67	41.38	652.1	595.8	4501	4395
28	50	1640	1560	51.36	49.67	924.3	774.8	4269	4432
29	50	1290	1290	58.03	57.79	748.6	745.5	4560	4534
30	50	1400	1390	54.18	48.23	758.5	670.4	4862	4687
31	50	1510	1490	36.94	33.46	557.7	498.6	4254	4406
32	50	1300	1270	43.04	40.86	559.6	519.2	4433	4503
33	50	1390	1320	45.22	41.39	628.5	546.3	4425	4207
34	50	1230	1220	57.02	52.75	701.3	643.6	4813	4859
35	50	1210	1210	57.65	53.35	697.6	645.5	4399	4530
36	50	1240	1240	56.28	55.86	697.9	692.7	4557	4660
37	HAY	890	720	80.84	85.69	683.9	616.9	3623	3537
38	HAY	840	690	72.16	87.67	606.2	604.9	4160	4161
39	HAY	820	700	72.45	86.46	613.6	605.3	3417	3773
40	HAY	620	580	83.80	83.61	519.6	508.2	4083	3588
41	HAY	900	730	75.22	87.43	677.0	638.2	4233	3955
42	HAY	850	670	75.31	85.99	640.1	576.1	3934	3875
43	HAY	820	660	71.34	85.13	594.0	561.9	3786	3939
44	HAY	820	670	75.35	86.45	617.9	579.2	4022	3604
45	HAY	830	710	72.54	86.69	602.1	615.5	4034	3882
46	HAY	730	756	84.53	89.49	617.1	676.5	3827	3858

Table A.4. Analysis of Variance of Dry Matter and Gross Energy Recovery at Feeding. Growing Cattle Experiment 2

Recovery, %	Source	df	Sum of Squares[a]	P
Dry matter				
	Trt	3	391.1	0.0122
	Error	42	1336	
Gross energy				
	Trt	3	142.5	0.4215
	Error	42	2083	

[a] Type III sum of squares.

Table A.5. Forage Characteristics at Harvest.
Growing Cattle Experiment 1

OBS	TRT	HBWT	HPDM	HPOM	IVOMD	HPCP	HGE
1	DC	1410	23.81	93.2	49.7	14.84	3786
2	DC	1360	31.43	93.6	50.55	15.38	4408
3	DC	1210	27.27	92.7	50.25	12.71	4881
4	DC	1180	21.07	94.25	48.65	14.26	4479
5	DC	1300	28.26	94.75	49.04	14.45	4933
6	DC	1350	22.20	94.2	50.35	16.97	4719
7	DC	1320	27.24	93.5	52.5	15.94	4155
8	DC	1290	25.58	94.55	41.6	13.39	4432
9	DC	1180	28.20	94.5	50.45	13.95	4187
10	DC	1370	26.73	94.3	50.25	13.59	4666
11	DC	1640	28.45	94.3	47.2	13.65	4542
12	DC	1320	23.02	94.1	48.15	14.53	4375
13	40	1270	32.45	94.45	48.9	15.96	4979
14	40	1420	30.67	94.55	40.95	16.58	3951
15	40	1340	32.65	94.6	45.55	16.08	4481
16	40	1330	30.86	94.85	39.7	16.17	4653
17	40	1380	47.50	94.65	47.9	16.19	3886
18	40	1470	50.53	94.5	47.9	15.49	3973
19	40	1280	34.56	94.4	49.55	15.44	4911
20	40	1290	33.56	94.4	50.95	15.24	3761
21	40	1240	31.35	94.45	50.75	14.64	4472
22	40	1360	36.67	94.75	51.9	14.98	4860
23	40	1320	40.06	94 42	55	14.65	4670
24	40	1330	39.24	94.3	47.85	15.25	4370
25	50	1190	42.83	94.2	47.1	14.46	4586
26	50	1380	51.00	94.55	49.4	13.21	4611
27	50	1730	69.52	94.55	50.5	13.27	4659
28	50	1080	73.86	94.55	52.6	12.48	4384
29	50	1350	43.78	94.6	52.05	13.22	4192
30	50	1330	48.76	94.6	48.7	12.14	4656
31	50	1220	58.84	93.85	50.25	11.28	4224
32	50	1470	41.91	94.35	51.25	13.22	4597
33	50	1370	49.60	94.25	51.45	14.03	4868
34	50	1240	45.12	94	51.25	14.21	4843
35	50	1270	45.36	94.4	52	13.64	4305
36	50	1130	53.21	94.1	51.05	14.90	4637
37	HAY	520	98.49	94.1	48.3	16.47	3768
38	HAY	640	84.49	94.3	45.9	14.76	4161
30	HAY	670	87.47	94.5	50.65	14.63	4018
40	HAY	630	88.03	94.35	49.9	16.51	3990
41	HAY	540	72.96	94.8	52.7	16.30	3992
42	HAY	660	87.37	94.55	49.2	16.03	4036
43	HAY	650	86.29	94.35	48.85	15.09	4322
44	HAY	670	89.47	94.55	52.35	17.28	4253
45	HAY	670	85.69	94.65	47.55	14.56	4006
46	HAY	650	81.73	94.85	51.8	15.81	4318
47	HAY	560	88.00	94.75	50.85	17.38	3981
48	HAY	560	90.32	94.5	51.65	15.85	3941

Table A.6. Analysis of Variance of Forage Characteristics at Harvest. Growing Cattle Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	25179	0.0001
	Error	44	2154	
Organic matter, %DM				
	Trt	3	2.10	0.0038
	Error	44	5.94	
Gross energy, kcal/g				
	Trt	3	1.62	0.4821
	Error	44	4.01	
Crude protein, %DM				
	Trt	3	48.01	0.0001
	Error	44	41.70	
IVOMD, %				
	Trt	3	88.19	0.0015
	Error	42	333.75	

[a] Type III sum of squares.

Table A.7. Forage Characteristics at Feeding.
Growing Cattle Experiment 1

OBS	TRT	FBWT	FPDM	FPOM	IVOMD	FPCP	FGE	FPNDF
1	DC	1180	24.32	89.65	40.45	18.18	4417	69.55
2	DC	1480	25.33	91.15	42.00	13.93	4854	67.60
3	DC	1150	24.53	93.15	44.20	14.14	4935	68.37
4	DC	1180	24.79	94.20	39.95	14.32	4574	68.57
5	DC	1370	24.01	93.00	43.80	14.44	5272	70.26
6	DC	1190	21.82	92.25	39.60	14.0	5457	72.42
7	DC	1150	24.66	92.60	45.05	14.41	5046	69.96
8	DC	1340	22.87	94.05	43.25	14.83	4719	68.65
9	DC	1180	24.40	93.45	40.45	14.50	4558	68.30
10	DC	1440	24.96	93.40	47.10	14.48	4699	68.97
11	DC	1520	23.15	92.40	43.15	14.75	4844	71.97
12	DC	1120	21.14	92.10	39.75	15.60	4245	69.10
13	40	1300	31.87	93.80	46.45	15.53	4633	69.26
14	40	1420	29.09	94.30	45.05	14.80	4350	71.70
15	40	1410	29.61	93.70	44.50	14.32	4111	70.91
16	40	1530	31.78	93.95	41.75	14.64	4615	70.62
17	40	1500	36.47	93.80	38.40	15.03	4312	71.25
18	40	1420	46.80	93.80	38.65	14.04	4399	69.97
19	40	1300	31.43	94.10	46.40	14.2	4682	72.29
20	40	1290	28.51	93.75	46.40	13.3	4097	71.92
21	40	1390	30.55	93.65	47.10	13.47	4447	70.36
22	40	1430	36.85	94.35	43.15	15.71	4642	73.56
23	40	1330	44.36	93.65	35.10	15.1	4787	69.63
24	40	1440	35.48	94.25	41.10	15.00	4595	72.21
25	50	1250	49.51	94.75	44.90	14.03	4251	72.68
26	50	1340	48.53	94.50	46.40	13.65	4358	71.33
27	50	1710	46.32	94.70	49.95	13.79	4680	73.72
28	50	1070	56.27	94.00	46.60	14.04	4405	72.70
29	50	1250	40.97	92.95	43.20	14.72	4787	73.59
30	50	1180	41.45	93.75	47.00	14.55	4516	71.68
31	50	1280	57.57	94.30	51.20	14.37	4593	63.87
32	50	1480	44.39	94.45	48.00	13.59	4537	70.01
33	50	1380	50.21	94.65	47.55	14.21	4162	70.27
34	50	1160	52.97	93.25	47.70	15.44	4234	70.28
35	50	1130	53.97	92.45	44.45	15.25	4372	69.39
36	50	1090	58.49	92.80	43.70	15.32	4973	72.26
37	HAY	620	87.72	94.80	48.60	15.27	4098	75.20
38	HAY	660	88.65	94.00	46.95	14.78	4043	75.11
39	HAY	660	89.05	94.10	47.50	14.59	4055	74.86
40	HAY	630	88.48	93.90	47.05	14.38	4219	75.59
41	HAY	660	88.28	94.50	47.95	13.54	.	74.54
42	HAY	640	86.78	94.30	47.30	13.20	4268	74.85
43	HAY	640	89.56	94.40	47.70	14.50	4199	74.61
44	HAY	640	87.25	94.30	46.45	14.36	4191	74.33
45	HAY	630	87.03	94.10	49.75	15.02	4211	73.30
46	HAY	630	89.83	94.00	47.60	15.18	4319	73.34
47	HAY	660	87.60	94.60	48.60	13.78	4177	73.78
48	HAY	600	89.09	94.10	49.50	13.56	4184	75.02

Table A.8. Analysis of Variance of Forage Characteristics at Feeding. Growing Cattle Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	28684	0.0001
	Error	44	813	
Organic matter, %DM				
	Trt	3	18.66	0.0001
	Error	44	26.70	
Gross energy, kcal/g DM				
	Trt	3	2.24	0.0001
	Error	43	2.58	
Crude protein, %DM				
	Trt	3	1.50	0.5458
	Error	44	30.70	
Neutral detergent fiber, %DM				
	Trt	3	165.0	0.0001
	Error	44	124.4	
IVOMD, %				
	Trt	3	18.66	0.0001
	Error	42	26.70	

[a] Type III sum of squares.

Table A.9. Forage Characteristics at Harvest.
Growing Cattle Experiment 2

OBS	TRT	HBWT	HPDM	HPOM	HGE	HPCP	IVOMD
1	DC	1700	28.99	91.50	4335	13.55	51.70
2	DC	1620	29.41	92.00	4072	12.18	50.45
3	DC	1400	34.29	93.60	4452	13.38	50.05
4	DC	1510	30.90	92.10	4025	14.73	49.30
5	DC	1550	31.77	93.80	4299	15.98	54.50
6	DC	1390	34.04	93.80	4459	15.38	55.05
7	DC	1610	28.78	93.50	4241	14.77	50.40
8	DC	1700	32.54	92.60	4246	12.51	48.85
9	DC	1480	29.91	92.80	4053	16.87	49.65
10	DC	1420	29.89	92.90	4834	13.42	47.95
11	DC	1500	28.49	94.50	4505	15.60	54.35
12	DC	1530	34.67	92.00	4299	13.33	52.55
13	40	1440	39.47	93.10	4689	16.90	47.45
14	40	1550	35.04	93.00	4753	15.90	48.80
15	40	1380	37.25	93.30	4709	14.61	49.00
16	40	1430	33.32	93.20	4325	10.53	48.75
17	40	1410	38.74	93.90	4605	14.76	52.35
18	40	1460	43.74	92.40	4484	14.01	51.00
19	40	1480	35.16	93.10	4743	11.87	47.85
20	40	1450	38.39	90.60	4597	13.55	47.90
21	40	1460	37.12	92.70	4491	14.54	46.10
22	40	1530	38.47	94.00	4562	11.83	48.40
23	40	1300	45.38	94.10	4596	14.09	49.95
24	40	1500	42.15	92.50	4645	14.60	51.00
25	50	1630	33.17	90.80	4342	14.09	52.15
26	50	1350	45.83	93.30	4658	9.27	48.30
27	50	1460	44.67	93.70	4501	9.80	50.90
28	50	1640	51.36	94.50	4269	11.53	53.05
29	50	1290	58.03	94.60	4560	10.24	52.40
30	50	1400	54.18	94.00	4862	12.48	52.05
31	50	1510	36.94	92.90	4254	16.21	51.35
32	50	1300	43.04	93.40	4433	12.68	52.00
33	50	1390	45.22	92.90	4425	10.58	46.30
34	50	1230	57.02	94.10	4813	13.00	54.65
35	50	1210	57.65	94.40	4399	12.34	50.50
36	50	1240	56.28	93.40	4557	13.03	48.60
37	HAY	890	80.84	94.00	3623	12.95	45.05
38	HAY	840	72.16	93.50	4160	16.40	49.40
39	HAY	820	72.45	93.30	3417	11.54	44.45
40	HAY	620	83.80	93.60	4083	14.14	47.00
41	HAY	900	75.22	94.20	4235	16.66	50.60
42	HAY	.	.	94.50	.	14.81	53.85
43	HAY	850	75.31	93.90	3934	13.69	45.80
44	HAY	820	71.34	93.70	3786	13.39	47.60
45	HAY	820	75.35	94.00	4022	12.37	46.70
46	HAY	830	72.54	93.10	4034	12.69	45.90
47	HAY	730	84.53	94.30	3827	16.62	52.75
48	HAY	.	.	93.00	.	15.17	53.60

Table A.10. Analysis of Variance of Forage Characteristics at Harvest. Growing Cattle Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	12485	0.0001
	Error	42	1196	
Organic matter, % DM				
	Trt	3	5.827	0.0660
	Error	44	33.20	
Gross energy, kcal/g DM				
	Trt	3	2.975	0.0001
	Error	42	1.728	
Crude protein, %DM				
	Trt	3	38.49	0.0106
	Error	44	134.3	
IVOMD, %				
	Trt	3	66.56	0.0238
	Error	44	281.2	

[a] Type III sum of squares.

Table A.11. Forage Characteristics at Feeding. Growing Cattle Experiment 2

OBS	TRT	FBWT	FPDM	FPOM	IVOMD	FPNDF	FGE	FPCP
1	DC	1610	27.80	90.90	38.05	70.37	4867	14.50
2	DC	1530	26.55	93.90	43.95	70.73	4591	13.28
3	DC	1370	30.72	93.50	39.50	70.10	4332	13.14
4	DC	1490	26.84	92.40	39.95	70.08	4587	13.26
5	DC	1620	30.56	93.90	50.85	64.76	4459	12.86
6	DC	1370	32.33	93.50	43.80	69.33	4514	13.55
7	DC	1540	24.16	88.10	39.60	71.37	4885	13.60
8	DC	1600	26.66	91.40	36.40	69.42	4353	12.95
9	DC	1420	27.44	91.80	37.00	69.56	4570	12.82
10	DC	1390	29.05	92.20	39.15	69.05	4747	12.22
11	DC	1470	27.71	94.00	47.50	64.12	4531	12.93
12	DC	1530	31.12	93.00	44.40	66.09	4590	13.40
13	40	1430	36.04	92.60	45.20	69.36	5138	13.30
14	40	1430	31.68	91.50	39.40	68.67	4304	13.69
15	40	1340	34.48	93.00	42.40	69.39	4690	13.14
16	40	1390	29.21	92.30	40.55	69.65	4658	12.84
17	40	1470	36.16	92.90	41.90	69.25	4223	14.81
18	40	1440	39.79	91.70	44.15	67.79	4814	14.57
19	40	1320	38.31	92.80	42.35	71.92	4564	13.40
20	40	1390	36.63	92.80	49.15	70.44	4713	13.37
21	40	1460	32.03	92.30	44.15	69.31	4536	12.84
22	40	1320	36.67	93.20	42.05	72.69	4886	13.44
23	40	1260	43.40	93.20	43.65	67.88	4794	13.51
24	40	1500	41.14	92.10	46.05	67.14	4199	14.49
25	50	1550	32.71	93.20	46.35	68.18	4426	14.04
26	50	1330	43.18	93.70	39.50	74.37	4674	12.05
27	50	1440	41.38	93.40	43.65	71.58	4395	12.12
28	50	1260	29.67	94.50	50.40	63.72	4432	13.26
29	50	1290	57.79	94.60	47.10	67.12	4534	14.61
30	50	1390	48.23	93.80	47.80	66.64	4687	14.02
31	50	1490	33.46	91.90	49.45	67.07	4406	13.71
32	50	1270	40.86	93.50	47.15	73.06	4503	13.43
33	50	1320	41.39	92.90	40.05	72.09	4207	13.43
34	50	1220	62.75	93.80	50.55	64.89	4859	13.87
35	50	1210	53.35	94.20	45.65	68.16	4530	13.76
36	50	1250	55.86	94.70	44.35	69.60	4660	13.57
37	HAY	720	85.69	93.80	42.50	75.15	3537	12.52
38	HAY	690	87.67	93.40	42.10	74.65	4161	12.06
39	HAY	630	84.32	93.60	41.40	76.13	.	12.09
40	HAY	700	86.46	93.30	40.60	75.12	3773	11.26
41	HAY	580	87.61	94.40	48.25	70.78	3588	11.57
42	HAY	730	87.43	94.30	44.90	72.94	3955	13.64
43	HAY	670	85.99	93.80	40.40	74.67	3877	13.08
44	HAY	660	85.13	93.30	40.60	76.58	3939	11.54
45	HAY	670	82.89	93.40	41.60	76.54	3604	11.43
46	HAY	660	86.97	93.40	42.75	76.51	.	12.18
47	HAY	710	86.69	94.20	47.00	72.44	3882	13.49
48	HAY	756	89.49	93.40	50.75	69.85	3858	12.14

Table A.12. Analysis of Variance of Forage Characteritics at Feeding. Growing Cattle Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	23961	0.0001
	Error	44	1521	
Organic matter, %DM				
	Trt	3	18.30	0.0015
	Error	44	44.21	
Gross energy, kcal/g DM				
	Trt	3	4.610	0.0001
	Error	42	1.870	
Crude protein, %DM				
	Trt	3	13.75	0.0001
	Error	44	21.22	
Neutral detergent fiber, %DM				
	Trt	3	251.9	0.0001
	Error	44	270.1	
IVOMD, %				
	Trt	3	113.6	0.0423
	Error	44	562.4	

[a] Type III sum of squares.

Table A.13. Silage Fermentation Characteristics.
Growing Cattle Experiment 1

OBS	TRT	FPDM	FPCP	PK1	PK2	AMM1	AMM2
1	25	21.14	15.61	24.8	36.3	10.08	14.10
2	25	23.48	15.61	10.8	31.5	3.99	12.22
3	25	21.82	14.03	30.0	20.7	13.14	8.04
4	25	27.24	14.76	32.0	32.6	10.69	12.06
5	25	21.82	14.03	22.0	35.1	9.65	13.40
6	25	24.53	14.15	28.1	35.3	11.07	13.48
7	25	24.66	14.41	41.5	29.8	16.15	11.56
8	25	23.78	14.84	18.6	17.6	7.22	6.51
9	25	25.44	13.94	28.4	37.9	11.00	14.94
10	25	24.32	18.19	33.9	21.7	10.60	9.52
11	25	23.78	14.84	20.9	32.0	7.98	10.69
12	25	25.33	13.94	21.0	30.9	8.17	13.53
13	25	24.01	14.44	36.8	10.6	14.30	3.91
14	25	23.78	14.84	18.0	27.5	6.98	10.84
15	25	23.95	13.94	13.4	25.4	5.43	10.33
16	25	25.33	13.94	37.9	10.9	14.75	3.39
17	25	27.81	18.19	35.5	13.5	9.62	5.47
18	25	25.04	14.84	18.4	20.8	6.81	8.09
19	25	24.01	14.44	21.4	38.2	8.31	14.87
20	25	24.53	14.15	37.4	41.0	14.74	15.95
21	25	25.04	14.84	32.6	35.1	12.06	9.51
22	25	23.78	14.84	21.3	40.8	8.13	12.76
23	25	27.98	15.45	10.6	27.9	3.30	10.81
24	40	31.87	15.53	43.5	31.2	12.06	8.60
25	40	29.09	14.80	28.7	24.2	9.12	7.58
26	40	26.84	13.48	32.0	21.4	11.46	5.83
27	40	37.87	14.80	18.4	36.9	4.37	11.64
28	40	29.61	14.32	28.9	36.5	9.28	10.12
29	40	30.55	13.48	30.9	35.8	10.20	9.12
30	40	28.51	13.32	33.6	32.4	12.05	11.61
31	40	31.87	15.53	31.2	15.4	8.60	3.66
32	40	31.43	15.53	21.6	20.1	5.88	5.57
33	40	30.65	14.22	34.3	23.8	10.82	6.24
34	40	31.87	15.53	18.8	28.9	5.21	9.28
35	40	35.48	14.22	31.0	30.4	8.12	10.04
36	40	36.83	15.26	15.4	32.5	3.66	11.66
37	40	36.47	14.22	36.4	17.9	9.27	4.26
38	40	30.81	14.22	23.8	29.4	7.46	9.35
39	50	56.27	14.05	7.9	9.3	1.31	1.84
40	50	48.53	13.66	24.4	30.5	4.91	4.87
41	50	44.39	13.59	27.7	16.6	6.15	2.65
42	50	50.21	14.22	14.8	8.0	2.72	1.32
43	50	45.59	14.55	9.3	29.8	1.84	5.23
44	50	50.21	14.22	9.9	28.0	1.82	6.22

Table A.13. "Continued"

45	50	46.32	14.22	8.7	20.0	1.74	4.03
46	50	48.49	15.32	32.5	26.9	5.70	5.37
47	50	49.51	14.04	21.4	16.4	4.15	3.18
48	50	52.97	15.45	29.0	14.5	4.63	2.74
49	50	52.97	15.45	17.9	14.0	2.86	2.85
50	50	42.95	14.55	11.0	11.3	2.31	2.37
51	50	47.93	14.04	26.7	8.6	5.33	1.72
52	50	47.02	13.80	13.9	14.5	2.83	2.66
53	50	49.15	14.04	13.8	9.6	2.61	1.76

OBS	TRT	AC1	AC2	BUT1	BUT2	LAC1	LAC2
1	25	1.07	1.06	0.67	0.02	0.00	0.00
2	25	1.75	1.87	1.45	0.03	0.00	0.00
3	25	1.34	1.32	0.84	0.02	0.00	0.00
4	25	1.78	1.79	0.00	0.00	0.00	0.00
5	25	0.81	0.74	0.85	0.02	1.94	0.00
6	25	0.79	0.73	0.85	0.02	0.00	0.00
7	25	1.03	1.00	0.07	0.00	1.75	0.00
8	25	1.72	1.73	0.18	0.00	0.00	0.00
9	25	2.52	2.71	0.87	0.02	0.00	0.00
11	25	2.30	3.30	0.52	0.01	0.00	0.00
12	25	0.85	0.84	0.00	0.00	0.00	0.00
13	40	0.64	0.61	0.00	0.00	0.00	0.00
14	40	0.70	0.60	0.82	0.00	0.87	0.00
15	40	0.89	1.08	0.00	0.00	1.07	0.00
16	40	1.19	1.23	0.00	0.00	0.00	0.00
17	40	0.00	0.00	0.12	0.00	0.24	0.00
18	40	0.45	0.47	0.00	0.00	1.24	0.00
19	40	1.01	1.02	1.48	0.03	0.00	0.00
20	40	0.43	0.41	0.07	0.00	1.75	0.00
21	40	0.83	0.83	0.18	0.00	0.00	0.00
22	40	0.15	0.19	0.87	0.02	0.00	0.00
23	40	1.05	1.05	0.52	0.01	1.09	0.00
24	40	1.29	1.11	0.00	0.00	0.00	0.01
25	50	0.14	0.14	0.04	0.00	0.00	0.00
26	50	0.14	0.14	0.04	0.00	0.00	0.00
27	50	0.26	0.58	0.02	0.00	0.00	0.00
28	50	0.02	0.02	0.00	0.00	1.10	0.00
29	50	0.13	0.17	0.11	0.00	0.00	0.00
30	50	0.01	0.01	0.00	0.00	0.00	0.00
31	50	0.01	0.01	0.00	0.00	1.44	0.00
32	50	0.07	0.07	0.17	0.00	0.00	0.01
33	50	0.17	0.16	0.00	0.00	0.67	0.00
34	50	0.20	0.19	0.00	0.00	0.00	0.00
35	50	0.20	0.20	0.82	0.02	0.87	0.00
36	50	0.65	0.63	0.23	0.00	1.26	0.00

Table A.14. Analysis of Variance of Silage Fermentation Characteristics. Growing Cattle Experiment 1

Characteristic	Sourcee	df	Sum of Squares	P
pH				
	Trt	2	11.76	0.0001
	Error	33	13.50	
Ammonia N, % total nitrogen				
	Trt	2	440.65	0.0001
	Error	50	165.14	
Lactic acid, %DM				
	Trt	2	2.60	0.6596
	Error	33	101.80	
Acetic acid, %DM				
	Trt	2	10.30	0.0001
	Error	33	7.43	
Butyric acid, %DM				
	Trt	2	0.53	0.0054
	Error	33	1.41	

[a] Type III sum of squares.

Table A.15. Silage Fermentation Characteristics.
Growing Cattle Experiment 2

OBS	TRT	FPDM	FPCP	PK1	PK2	AMM1	AMM2
1	25	27.44	12.82	22.1	22.4	8.57	8.68
2	25	27.8	13.63	25.1	25.9	9.13	9.42
3	25	29.05	12.22	37.6	38.1	13.70	13.88
4	25	26.55	13.28	32.7	30.8	12.37	11.65
5	25	24.16	13.60	30.5	30.9	12.84	13.01
6	25	27.44	12.82	40.9	42.5	15.06	15.65
7	25	32.33	13.55	33.8	33.6	10.57	10.51
8	25	31.12	13.40	19.4	18.9	6.38	6.22
9	25	31.12	13.40	35.0	35.4	11.51	11.65
10	25	30.56	12.86	31.5	30.5	10.35	10.02
11	25	26.66	12.95	25.9	13.0	9.93	5.08
12	25	26.66	12.95	13.6	26.5	5.31	10.16
13	25	27.71	12.93	35.7	35.8	13.72	13.76
14	40	43.40	13.51	23.3	23.2	5.38	5.36
15	40	39.79	14.57	30.5	30.4	6.87	6.85
16	40	41.14	14.49	26.4	26.7	6.01	6.08
17	40	38.31	13.40	18.9	18.9	4.85	4.85
18	40	38.31	13.40	35.0	33.9	8.99	8.70
19	40	31.68	13.37	30.5	28.6	9.48	8.89
20	40	32.03	12.84	14.6	15.0	4.76	4.89
21	40	32.03	12.84	38.3	39.4	12.78	13.15
22	40	34.48	13.14	45.6	31.2	13.34	9.12
23	40	36.16	14.81	43.5	42.4	10.81	10.53
24	40	29.21	12.84	30.0	28.1	10.34	9.69
25	40	45.59	13.44	24.1	23.5	5.14	5.02
26	40	34.45	13.14	31.4	46.0	9.18	13.45
28	40	36.67	13.44	22.9	23.9	6.09	6.35
29	50	41.38	12.05	21.9	21.9	5.94	5.94
30	50	40.86	13.43	36.8	35.1	8.74	8.34
31	50	40.86	13.43	24.7	31.0	5.87	7.37
32	50	55.86	13.57	34.0	34.2	5.81	5.85
33	50	43.18	12.05	21.0	21.4	5.25	5.35
34	50	43.18	12.05	34.9	34.7	8.73	8.68
35	50	42.58	13.43	12.8	21.4	2.94	4.92
36	50	48.23	14.02	20.2	20.1	4.03	4.01
37	50	33.46	14.04	45.9	46.6	13.39	13.59
38	50	32.71	14.04	58.0	47.4	16.61	13.57
39	50	42.58	13.43	21.3	12.8	4.89	2.94
40	50	41.38	12.12	27.8	25.2	7.08	6.42
41	50	41.39	13.43	19.8	19.5	4.69	4.61
42	50	57.02	13.87	12.9	13.0	2.05	2.05
43	50	57.02	13.87	20.4	17.5	3.24	2.78
44	50	29.67	13.26	20.1	19.5	6.60	6.41
45	50	57.79	14.61	12.9	18.3	2.04	3.33
46	50	53.55	13.76	18.6	13.6	3.38	2.16

Table A.14. "Continued"

OBS	TRT	AC1	AC2	BUT1	BUT2	LAC1	LAC2
1	25	1.57	1.58	0.83	0.00	1.02	0.00
2	25	1.49	1.47	0.39	0.00	3.18	0.00
3	25	0.81	0.86	0.44	0.00	0.70	0.00
4	25	0.00	0.01	0.01	0.00	1.06	0.00
5	25	1.37	1.27	0.33	0.00	1.19	0.01
6	25	0.33	0.31	0.00	0.00	0.00	0.01
7	25	1.41	1.45	0.00	0.00	0.14	0.00
8	25	1.67	1.75	0.00	0.00	1.49	0.00
9	25	1.80	1.78	0.00	0.00	0.42	0.00
10	25	0.84	0.83	0.00	0.00	3.01	0.00
11	25	1.15	1.13	0.00	0.00	0.00	0.00
12	25	1.47	1.52	0.03	0.00	1.18	0.00
13	40	0.85	0.00	0.11	0.00	0.47	0.00
14	40	0.84	0.00	0.02	0.00	0.00	0.00
15	40	0.47	0.00	0.06	0.00	0.00	0.00
16	40	1.27	0.00	0.00	0.00	0.00	0.00
17	40	0.43	0.00	0.00	0.00	1.11	0.00
18	40	0.84	0.00	0.12	0.00	0.00	0.00
19	40	0.36	0.00	0.05	0.00	0.29	0.00
20	40	0.59	0.00	0.20	0.00	0.25	0.00
21	40	0.17	0.00	0.13	0.00	0.00	0.00
22	40	0.32	0.00	0.00	0.00	0.00	0.00
23	40	0.21	0.00	0.09	0.00	0.46	0.00
24	40	0.48	0.00	0.02	0.00	0.00	0.00
25	50	1.19	0.00	0.00	0.00	0.15	0.00
26	50	0.99	0.00	1.10	0.00	0.14	0.00
27	50	0.13	0.00	0.03	0.00	0.00	0.00
28	50	0.32	0.00	0.00	0.00	0.00	0.00
29	50	1.16	0.00	0.86	0.00	1.03	0.00
30	50	0.27	0.00	0.04	0.00	0.11	0.00
31	50	0.11	0.00	0.03	0.00	1.47	0.00
32	50	0.36	0.00	0.21	0.00	0.59	0.00
33	50	0.33	0.00	0.01	0.00	0.00	0.00
34	50	0.12	0.00	0.05	0.00	0.00	0.00
35	50	0.82	0.00	0.04	0.00	0.00	0.00
36	50	0.20	0.00	0.00	0.00	0.00	0.00

Table A.16. Analysis of Variance of Silage Fermentation Characteristics. Growing Cattle Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
pH				
	Trt	2	0.88	0.0648
	Error	33	4.90	
Ammonia N, % total nitrogen				
	Trt	2	162.30	0.0009
	Error	42	410.20	
Lactic acid, %DM				
	Trt	2	11.60	0.0105
	Error	33	36.42	
Acetic acid, %DM				
	Trt	2	6.40	0.0001
	Error	33	4.20	
Butyric acid, %DM				
	Trt	2	0.03	0.4630
	Error	33	0.60	

[a] Type III sum of squares.

Table A.17. Forage Intake. Growing Cattle Experiment 1

TRT	PEN	SW1	SW2	HDAY	FPDM	FOFF	DMOF	FCON	DMCN	DML	GE	GED
25	7	558	536	870	25.59	38.13	9.76	35.34	9.08	6.98	4.8	50.4
25	8	560	552	870	25.63	40.59	10.40	37.49	9.32	10.35	4.8	50.4
85	4	566	633	874	87.68	14.02	12.29	13.22	11.64	5.25	4.1	53.0
85	6	549	594	871	87.97	13.00	11.43	10.75	10.38	9.19	4.1	53.0
40	1	543	567	870	36.03	32.24	11.62	29.91	10.76	7.36	4.5	48.1
40	5	555	552	869	35.26	30.63	10.80	26.90	9.61	11.0	4.5	48.1
50	2	551	730	869	48.04	24.70	11.86	22.47	10.91	8.1	4.5	50.8
50	3	542	566	867	47.71	27.92	13.32	24.48	10.93	18.0	4.5	50.8

Table A.18. Analysis of Variance of Forage Intake. Growing Cattle Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	4468	0.0001
	Error	4	0.394	
Dry matter losses, % DM fed				
	Trt	3	36.84	0.5955
	Error	4	69.37	
Dry matter intake, kg/day				
	Trt	3	0.870	0.1154
	Error	4	0.310	
Dry matter intake, % BW				
	Trt	3	0.089	0.1028
	Error	4	0.029	
Dry matter intake, g/kg $BW^{0.75}$				
	Trt	3	155.4	0.1065
	Error	4	51.63	
Gross energy intake, kcal/kg $BW^{0.75}$				
	Trt	3	2.00	0.2144
	Error	4	1.00	
Digestible energy intake, kcal/kg $BW^{0.75}$				
	Trt	3	1.00	0.1266
	Error	4	2.00	
Metabolizable energy intake, kcal/kg $BW^{0.75}$				
	Trt	3	1.00	0.1266
	Error	4	2.00	

[a] Type III sum of squares.

Table A.19. Forage Intake. Growing Cattle Experiment 2

TTR	PEN	SW1	SW2	FPDM	FOFF	DMOFF	FCON	DMCN	DML	GE	GED
25	3	483	442	27.68	33.53	9.28	28.78	8.04	13.42	4.58	51.4
25	8	515	489	28.30	30.91	8.75	27.91	7.91	9.60	4.58	51.4
40	2	513	487	36.49	29.26	10.67	24.05	8.90	16.62	4.46	51.0
40	7	511	498	36.89	28.86	10.65	23.36	8.97	15.71	4.46	51.0
50	1	518	527	42.51	26.90	11.43	21.29	9.42	17.64	4.53	52.1
50	5	600	530	45.18	27.76	12.54	19.05	9.60	23.43	4.53	52.1
85	4	515	517	86.87	11.90	10.34	8.90	8.38	18.96	3.82	51.0
85	6	531	537	86.98	12.35	10.74	9.20	8.98	16.40	3.82	51.0

Table A.20. Analysis of Variance of Forage Intake. Growing Cattle Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	4116	0.0001
	Error	4	3.843	
Dry matter losses, % DM fed				
	Trt	3	85.37	0.1031
	Error	4	27.75	
Dry matter intake, kg/day				
	Trt	3	0.500	0.0113
	Error	4	0.043	
Dry matter intake, % BW				
	Trt	3	0.025	0.3138
	Error	4	0.020	
Dry matter intake, g/kg $BW^{0.75}$				
	Trt	3	50.22	0.1370
	Error	4	20.03	
Gross energy intake, Kcal/kg $BW^{0.75}$				
	Trt	3	10.00	0.0085
	Error	4	1.00	
Digestible energy intake, Kcal/kg $BW^{0.75}$				
	Trt	3	2.00	0.0066
	Error	4	1.00	
Metabolizable energy intake, Kcal/kg $BW^{0.75}$				
	Trt	3	1.00	0.0066
	Error	4	0.10	

[a] Type III sum of squares.

Table A.21. Bodyweight and Average Daily Gain.
Growing Cattle Experiment 1

TRT	PEN	FW1	SW1	PS1	FW2	FW3	FW4	FW5	SW2	FW6	FILL	FAWT
25	2	602	560	6.8	616	609	601	589	552	564	8.3	601
25	1	598	558	6.7	602	597	584	576	536	548	8.7	588
40	1	587	543	7.6	592	606	601	615	567	579	29.0	606
40	2	597	555	6.8	586	603	597	594	552	566	6.8	607
50	2	583	542	7.1	576	614	615	614	566	561	18.1	616
50	1	592	551	7.0	602	624	622	620	573	582	18.3	622
85	1	607	566	6.8	621	656	673	685	633	624	41.6	663
85	2	596	549	7.8	615	632	618	642	594	575	31.8	631

TRT	PEN	KCS1	BCS1	KCS2	BCS2	FILL	WCHP1	WCHP2	WCHP3	AHCG
25	2	8.5	7.6	6.5	6.5	20.5	1.02	-0.24	-0.30	0.19
25	1	8.3	7.3	6.4	6.4	19	0.24	-0.15	-0.48	0.19
40	1	7.8	6.9	6.3	6.4	16.2	0.37	0.49	-0.18	0.93
40	2	8.5	7.2	7.0	6.8	17.7	-0.81	0.63	-0.22	0.74
50	2	8.0	7.7	6.8	6.7	19.9	-0.54	1.34	0.04	0.81
50	1	8.1	7.1	7.0	7.0	18.1	0.70	0.77	-0.07	0.90
85	1	8.4	7.3	7.4	7.4	15.3	1.00	1.26	0.59	1.00
85	2	8.2	7.3	7.0	7.0	17.9	1.34	0.61	-0.49	1.00

TRT	PEN	WCG1	WCG2	WCG3	SWCG	AWCHG	HDAY	FPDM	DMCN	DML	GE	GED
25	2	0.18	-0.01	-0.14	-0.09	-0.01	870	25.6	9.32	10.4	4.6	50.4
25	1	-0.02	-0.20	-0.26	-0.25	-0.12	870	25.6	9.08	7.0	4.6	50.4
40	1	0.45	0.20	0.32	0.28	0.21	870	36.0	10.76	7.4	4.5	50.4
40	2	0.15	0.00	-0.03	-0.03	0.12	869	35.3	9.61	11.0	4.5	50.4
50	2	0.71	0.44	0.34	0.28	0.37	867	47.7	10.93	18.0	4.5	48.1
50	1	0.75	0.42	0.32	0.26	0.34	869	48.0	10.91	8.1	4.5	48.1
85	1	1.18	0.94	0.89	0.78	0.64	874	87.7	11.64	5.3	3.8	50.8
85	2	0.85	0.31	0.53	0.52	0.40	871	88.0	10.38	9.2	3.8	50.8

Table A.22. Analysis of Variance of Bodyweight and Average Daily Gain. Growing Cattle Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Initial shrunk weight, kg				
	Trt	3	759.1	0.8353
	Pen(Trt)	4	3562	0.7883
Height change, cm				
	Trt	3	7.87	0.0050
	Error	76	43.04	
Body condition score change				
	Trt	3	16.85	0.0186
	Pen(Trt)	4	1.90	0.8594
Daily gain, kg				
Full				
	Trt	3	1.80	0.0192
	Pen(Trt)	4	0.21	0.0304
Shrunk				
	Trt	3	1.44	0.0183
	Pen(Trt)	4	0.16	0.0312
Adjusted				
	Trt	3	0.79	0.0171
	Pen(Trt)	4	0.08	0.3090

[a] Type III sum of squares.

Table A.23. Bodyweight and Average Daily Gain.
Growing Cattle Experiment 2

TRT	PEN	FW1	SW1	PS1	FW2	FW3	FW4	FW5	SW2	PS2	FW6	FW7	FILL	FAWT
25	3	517	483	6.6	504	484	455	478	442	7.4	474	485	-4	489
25	8	548	515	6.7	540	528	509	535	489	8.5	515	519	-20	530
40	2	541	511	5.7	524	545	510	541	498	8.0	510	544	-31	525
40	7	541	513	5.2	540	535	518	517	487	5.8	515	524	-2	530
50	1	546	522	4.4	546	558	546	566	530	6.4	549	549	-17	564
50	5	555	518	6.8	553	557	554	560	527	6.0	555	573	-6	570
85	4	548	515	6.1	547	552	533	553	517	6.6	530	554	-23	545
85	6	557	531	4.6	558	574	551	576	537	6.7	555	560	-21	570

TRT	PEN	CSA1	CSA2	CSK1	CSA3	CSK2	AHCG
25	3	8.2	7.7	7.2	6.8	5.6	0.88
25	8	7.8	7.8	6.6	6.8	5.9	1.19
40	2	8.2	7.6	7.0	7.0	5.9	0.98
40	7	8.5	8.0	7.1	6.8	6.4	0.99
50	1	8.4	8.0	6.7	7.4	6.4	0.90
50	5	8.3	7.9	6.9	7.3	6.3	1.01
85	4	8.3	7.8	6.9	7.1	5.7	0.91
85	6	8.3	8.1	7.3	7.6	6.6	1.44

TRT	PEN	SWCHG	WCHG3	AWCHG	FPDM	DMCN	DML
25	3	-0.4	-0.37	-0.3	27.68	8.04	13.42
25	8	-0.3	-0.29	-0.2	28.30	7.91	9.60
40	2	-0.1	-0.27	-0.2	36.49	8.90	16.62
40	7	-0.3	-0.22	-0.1	36.89	8.97	15.71
50	1	0.08	0.02	0.2	42.51	9.42	17.64
50	5	0.09	-0.00	0.2	45.18	9.60	23.43
85	4	0.02	-0.16	-0.0	86.87	8.38	18.96
85	6	0.07	-0.02	0.1	86.98	8.98	16.40

Table A.24. Analysis of Variance of Bodyweight and Average Daily Gain. Growing Cattle Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Initial shrunk weight, kg				
	Trt	3	1388	0.3691
	Pen(Trt)	4	1337	0.8076
Height change, inches				
	Trt	3	2.24	0.4041
	Pen(Trt)	4	2.39	0.4699
Body condition score change				
	Trt	3	5.24	0.4570
	Pen(Trt)	4	6.55	0.0520
Daily gain, kg				
Full				
	Trt	3	0.465	0.1252
	Pen(Trt)	4	0.174	0.0170
Shrunk				
	Trt	3	0.499	0.0115
	Pen(Trt)	4	0.043	0.5145
Adjusted				
	Trt	3	0.465	0.0170
	Pen(Trt)	4	0.174	0.1257

[a] Type III sum of squares.

Table A.25. Digestibility of Nutrients. Sheep experiment 1

AN	TRT	AFED	ORT	FCS	%DMF	%DMO	%DMFS	%OMF	%OMO	%OMFS	GEF
106	DC	30.0	5.8	7.1	20.8	20.6	39.2	92.5	90.7	91.8	4.8
107	DC	31.0	3.0	8.1	20.8	20.6	41.3	92.5	90.7	91.3	4.8
129	DC	30.3	2.2	9.9	20.8	20.6	35.2	92.5	90.7	90.1	4.8
109	DC	28.0	5.5	6.2	20.8	20.6	42.2	92.5	90.7	92.1	4.8
119	DC	28.7	7.9	6.1	20.8	20.6	37.7	92.5	90.7	91.8	4.8
131	DC	31.9	3.5	8.2	20.8	20.6	41.6	92.5	90.7	92.2	4.8
108	40	18.5	0.6	10.2	32.4	35.2	31.1	93.2	92.1	90.1	4.5
114	40	20.6	0.7	9.5	32.4	35.2	34.0	93.2	92.1	91.0	4.5
116	40	23.4	3.5	9.9	32.4	35.2	33.2	93.2	92.1	91.7	4.5
126	40	20.9	1.3	10.3	32.4	35.2	35.3	93.2	92.1	92.6	4.5
110	40	20.0	0.6	10.2	32.4	35.2	29.5	93.2	92.1	91.6	4.5
122	40	19.9	0.2	10.2	32.4	35.2	32.5	93.2	92.1	92.5	4.5
128	50	17.4	5.3	8.2	46.2	49.5	35.6	93.7	92.9	91.6	4.2
112	50	17.3	3.1	11.4	46.2	49.5	31.1	93.7	92.9	91.0	4.2
102	50	17.3	5.8	7.2	46.2	49.5	39.0	93.7	92.9	92.0	4.2
113	50	17.8	4.2	9.6	46.2	49.5	33.9	93.7	92.9	94.0	4.2
120	50	15.4	4.1	7.6	46.2	49.5	37.0	93.7	92.9	92.0	4.2
115	50	18.6	3.6	10.9	46.2	49.5	32.1	93.7	92.9	91.1	4.2
117	HAY	7.8	0.8	9.0	79.2	84.4	31.4	93.7	93.4	92.2	4.3
121	HAY	8.7	0.7	8.8	79.2	84.4	37.8	93.7	93.4	91.1	4.3
105	HAY	12.6	2.2	14.1	79.2	84.4	33.0	93.7	93.4	91.7	4.3
103	HAY	10.2	2.6	8.1	79.2	84.4	35.1	93.7	93.4	93.2	4.3
124	HAY	9.6	4.5	4.2	79.2	84.4	46.0	93.7	93.4	91.4	4.3
111	HAY	6.9	2.1	7.4	79.2	84.4	32.4	93.7	93.4	91.4	4.3

Table A.25. "Continued"

AN	TRT	GEO	GEFS	%CPF	%CPO	%CPFS	%NDFF	%NDFO	%NDFFS
106	DC	4.6	4.6	11.30	12.35	7.65	70.17	70.86	75.26
107	DC	4.6	4.5	11.30	12.35	7.34	70.17	70.86	73.04
129	DC	4.6	4.1	11.30	12.35	7.34	70.17	70.86	73.16
109	DC	4.6	4.4	11.30	12.35	7.22	70.17	70.86	72.13
119	DC	4.6	4.0	11.30	12.35	6.83	70.17	70.86	72.58
131	DC	4.6	4.3	11.30	12.35	7.28	70.17	70.86	73.51
108	40	4.2	4.2	12.06	11.63	8.38	72.01	82.34	73.38
114	40	4.2	4.2	12.06	11.63	7.61	72.01	82.34	77.02
116	40	4.2	4.3	12.06	11.63	7.43	72.01	82.34	74.33
126	40	4.2	3.9	12.06	11.63	6.88	72.01	82.34	77.61
110	40	4.2	3.3	12.06	11.63	7.51	72.01	82.34	72.79
122	40	4.2	4.1	12.06	11.63	5.58	72.01	82.34	74.34
128	50	4.7	4.0	10.76	11.22	7.00	75.45	80.16	75.96
112	50	4.7	3.8	10.76	11.22	4.83	75.45	80.16	73.93
102	50	4.7	4.0	10.76	11.22	5.84	75.45	80.16	71.53
113	50	4.7	3.9	10.76	11.22	7.20	75.45	80.16	79.14
120	50	4.7	3.6	10.76	11.22	6.08	75.45	80.16	76.65
115	50	4.7	4.0	10.76	11.22	6.86	75.45	80.16	73.50
117	HAY	4.3	4.1	11.77	12.61	11.67	74.82	85.71	70.58
121	HAY	4.3	4.1	11.77	12.61	6.18	74.82	85.71	74.91
105	HAY	4.3	3.7	11.77	12.61	6.89	74.82	85.71	76.30
103	HAY	4.3	4.3	11.77	12.61	12.49	74.82	85.71	74.30
124	HAY	4.3	4.2	11.77	12.61	9.86	74.82	85.71	71.54
111	HAY	4.3	3.5	11.77	12.61	7.09	74.82	85.71	73.66

Table A.26. Analysis of Variance of Digestibility of Nutrients. Sheep Experiment 1

Digestibility	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	50.17	0.3411
	Error	20	282.6	
Organic matter, %				
	Trt	3	55.0	0.2716
	Error	20	261.7	
Neutral detergent fiber, %				
	Trt	3	67.88	0.4010
	Error	20	439.8	
Gross energy, %				
	Trt	3	73.05	0.1792
	Error	20	270.2	
Crude protein, %				
	Trt	3	447.8	0.0158
	Error	20	680.1	

[a] Type III sum of squares.

Table A.27. Digestibility of Nutrients. Sheep Experiment 2

AN	TRT	AFED	ORT	FCS	%DMF	%DMO	%DMFS	%OMF	%OMO	%OMFS	GEF
355	DC	13.5	2.42	3.96	27.2	30.9	40.4	90.8	88.5	86.8	4.9
189	DC	16.0	5.84	3.42	27.2	30.9	46.5	90.8	88.5	86.8	4.9
372	DC	13.3	2.22	3.40	27.2	30.9	51.9	90.8	88.5	86.1	4.9
363	DC	13.7	1.81	3.55	27.2	30.9	54.5	90.8	88.5	85.4	4.9
359	DC	13.9	4.99	1.92	27.2	30.9	61.3	90.8	88.5	85.2	4.9
360	DC	11.6	1.47	3.41	27.2	30.9	49.5	90.8	88.5	85.3	4.9
361	40	9.7	1.54	2.96	35.0	36.7	47.2	92.6	85.5	89.6	4.7
356	40	11.8	2.83	3.85	35.0	36.7	43.6	92.6	85.5	90.3	4.7
366	40	8.9	1.10	2.88	35.0	36.7	51.3	92.6	85.5	87.8	4.7
371	40	11.9	0.15	4.79	35.0	36.7	42.3	92.6	85.5	88.2	4.7
364	40	10.6	0.38	3.99	35.0	36.7	45.8	92.6	85.5	88.3	4.7
362	40	9.0	0.0	4.06	35.0	36.7	47.0	92.6	85.5	85.7	4.7
354	50	9.2	0.0	4.76	41.8	45.1	42.5	93.1	85.8	90.0	4.8
370	50	9.2	1.14	9.20	41.8	45.1	20.7	93.1	85.8	85.5	4.8
351	50	6.8	0.04	3.32	41.8	45.1	44.4	93.1	85.8	89.2	4.8
374	50	7.1	0.0	3.32	41.8	45.1	42.4	93.1	85.8	88.3	4.8
368	50	6.7	0.35	3.09	41.8	45.1	44.2	93.1	85.8	88.9	4.8
353	50	8.4	1.25	3.64	41.8	45.1	46.4	93.1	85.8	90.1	4.8
367	hay	5.4	0.54	5.43	86.1	79.4	48.1	93.4	85.9	92.7	4.4
365	hay	4.3	0.18	4.84	86.1	79.4	38.1	93.4	85.9	92.1	4.4
375	hay	4.7	0.16	4.80	86.1	79.4	40.0	93.4	85.9	89.6	4.4
181	hay	5.2	0.03	5.86	86.1	79.4	39.7	93.4	85.9	85.7	4.4
373	hay	3.4	0.22	3.04	86.1	79.4	46.2	93.4	85.9	89.7	4.4
358	hay	3.6	0.06	3.48	86.1	79.4	45.2	93.4	85.9	89.6	4.4

Table A.27. "Continued"

AN	PEN	TRT	GEO	GEFS	%CPF	%CPO	%CPFS	%NDFF	%NDFO	%NDFFS
355	4	DC	4.3	4.3	10.5	8.5	7.9	70.1	72.8	66.6
189	7	DC	4.3	4.5	10.5	8.5	8.0	70.1	72.8	71.9
372	14	DC	4.3	4.0	10.5	8.5	5.9	70.1	72.8	77.9
363	16	DC	4.3	4.2	10.5	8.5	6.7	70.1	72.8	71.7
359	20	DC	4.3	4.0	10.5	8.5	6.3	70.1	72.8	74.8
360	22	DC	4.3	4.0	10.5	8.5	6.4	70.1	72.8	55.5
361	5	40	4.1	4.7	10.7	8.4	10.2	66.6	74.5	63.1
356	8	40	4.1	4.5	10.7	8.4	9.5	66.6	74.5	71.8
366	11	40	4.1	4.3	10.7	8.4	9.3	66.6	74.5	75.8
371	17	40	4.1	4.6	10.7	8.4	7.8	66.6	74.5	66.0
364	18	40	4.1	4.4	10.7	8.4	6.6	66.6	74.5	74.1
362	24	40	4.1	4.1	10.7	8.4	7.5	66.6	74.5	75.1
354	1	50	3.8	4.4	10.2	7.5	8.5	69.5	74.0	75.5
370	2	50	3.8	4.2	10.2	7.5	5.9	69.5	74.0	71.4
351	10	50	3.8	4.4	10.2	7.5	7.9	69.5	74.0	70.4
374	12	50	3.8	4.7	10.2	7.5	7.4	69.5	74.0	73.5
368	13	50	3.8	4.4	10.2	7.5	6.6	69.5	74.0	73.8
353	21	50	3.8	4.4	10.2	7.5	6.9	69.5	74.0	73.4
367	3	hay	3.2	4.3	8.6	7.1	8.6	71.6	72.0	75.5
365	6	hay	3.2	4.2	8.6	7.1	9.9	71.6	72.0	72.5
375	9	hay	3.2	4.3	8.6	7.1	9.7	71.6	72.0	76.9
181	15	hay	3.2	4.1	8.6	7.1	10.2	71.6	72.0	81.3
373	19	hay	3.2	4.1	8.6	7.1	8.0	71.6	72.0	71.4
358	23	hay	3.2	4.1	8.6	7.1	7.6	71.6	72.0	75.5

Table A.28. Analysis of Variance of Digestibility of Nutrients. Sheep Experiment 2

Digestibility	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	174.61	0.0561
	Error	20	390.99	
Organic matter, %				
	Trt	3	123.92	0.1086
	Error	20	359.68	
Neutral detergent fiber, %				
	Trt	3	65.44	0.6871
	Error	20	874.08	
Gross energy, %				
	Trt	3	6.33	0.9158
	Error	20	249.40	
Crude protein, %				
	Trt	3	1313	0.0012
	Error	19	1047	

[a] Type III sum of squares.

Table A.29. Nitrogen Utilization.
Sheep Experiment 2

AN	PEN	TRT	CPINT	CPFCS	AMURN	PCPUN	CPURN
355	4	DC	340	138	9390	3.48	327
189	7	DC	334	133	9321	3.12	290
372	14	DC	339	101	8900	3.77	336
363	16	DC	360	117	10380	3.11	323
359	20	DC	307	79	7735	3.75	290
360	22	DC	307	115	7575	3.84	291
361	5	40	348	182	7189	3.78	272
356	8	40	334	165	6325	3.85	243
366	11	40	333	180	10220	2.94	301
371	17	40	496	175	9375	3.56	334
364	18	40	431	125	7360	3.37	242
362	24	40	380	136	10805	2.78	301
354	1	50	418	172	11680	3.24	379
370	2	50	370	124	565	2.54	14
351	10	50	314	122	4330	3.87	167
374	12	50	325	122	9485	3.03	287
368	13	50	294	95	3080	4.24	131
353	21	50	330	117	5225	3.63	189
367	3	hay	393	237	2180	5.01	109
365	6	hay	330	192	2280	5.59	127
375	9	hay	358	190	5610	3.29	184
181	15	hay	403	261	14870	2.73	406
373	19	hay	251	125	4365	3.05	133
358	23	hay	281	125	4310	3.41	147

Table A.30. Analysis of Variance of Nitrogen Utilization. Sheep Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Nitrogen intake, g/day				
	Trt	3	0.00	0.2058
	Error	19	0.00	
Fecal nitrogen, g/day				
	Trt	3	0.00	0.0117
	Error	19	0.00	
Urinary nitrogen, g/day				
	Trt	3	0.00	0.0023
	Error	19	0.00	
Nitrogen retention, g/day				
	Trt	3	0.00	0.0495
	Error	19	0.00	
Nitrogen absorbed, g/day				
	Trt	3	0.00	0.0171
	Error	19	0.00	
Urinary N:N absorbed, %				
	Trt	3	17188	0.060
	Error	19	37148	

[a] Type III sum of squares.

Table A.31. Forage Characteristics. Cow Experiment 1

OBS	TRT	FBWT	PEN	FPDM	FPCP	FPOM	IVOMD
1	DC	1400	1	29.20	11.56	93.8	46.4
2	DC	1370	1	24.26	10.02	92.4	32.3
3	DC	1430	1	24.20	10.20	91.6	36.4
4	DC	1390	1	27.88	8.50	93.0	39.2
5	DC	1200	1	25.78	9.34	93.3	38.1
6	DC	1450	2	30.10	9.197	95.0	38.0
7	DC	1400	2	25.15	8.88	93.0	38.1
8	DC	1440	2	24.15	10.22	93.1	40.4
9	DC	1250	2	26.20	11.86	92.9	42.6
11	DC	1250	2	26.21	11.84	91.5	34.1
12	40	1630	1	34.12	10.76	93.1	43.8
13	40	1590	1	39.26	10.07	93.0	43.7
14	40	1420	1	31.10	7.91	95.1	38.4
15	40	920	1	30.07	10.52	95.1	32.7
16	40	1440	1	36.65	11.57	92.5	46.2
17	40	1760	2	38.68	8.26	91.3	33.7
18	40	1590	2	41.97	9.56	94.2	34.6
19	40	1680	2	34.18	10.06	93.8	50.5
20	40	1100	2	34.59	8.85	94.7	37.2
21	40	1770	2	30.59	8.84	92.1	42.3
22	50	1230	1	42.58	9.39	94.8	36.0
23	50	1520	1	40.95	11.02	90.4	41.4
24	50	1490	1	44.96	11.04	93.7	38.5
25	50	1400	1	56.53	10.59	93.8	47.9
26	50	1300	1	52.70	10.28	93.7	30.8
27	50	1240	2	50.76	10.28	94.1	36.2
28	50	1370	2	47.21	10.44	93.4	42.9
29	50	1390	2	45.22	11.14	93.3	40.5
30	50	1550	2	50.85	8.91	93.8	47.4
31	50	860	2	57.10	8.30	94.7	33.7
32	HAY	1010	1	82.92	9.40	94.0	40.2
33	HAY	530	1	84.13	7.48	94.5	43.3
34	HAY	840	1	87.46	7.86	96.0	40.4
35	HAY	910	1	85.82	8.57	94.1	35.9
36	HAY	1000	1	86.01	6.87	94.5	34.6
37	HAY	640	2	85.35	8.67	95.5	39.4
38	HAY	980	2	87.19	10.82	93.8	39.5
39	HAY	1090	2	82.93	10.23	93.9	40.0
40	HAY	530	2	88.44	9.23	95.0	44.4
41	HAY	980	2	80.20	11.53	94.4	41.0

Table A.32. Analysis of Variance of Forage Characteristics. Cow Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	4	20075	0.0001
	Error	35	512.19	
Organic matter, %DM				
	Trt	4	13.55	0.0206
	Error	35	42.71	
Crude protein, %DM				
	Trt	4	7.97	0.1798
	Error	35	53.89	
IVOMD, %				
	Trt	4	16.59	0.8701
	Error	35	817.56	

[a] Type III sum of squares.

Table A.33. Forage Characteristics.
Cow Experiment 2

TRT	PEN	BALE	FBWT	FPDM	FPOM	IVOMD	FPCP
DC	1	395	1500	30.59	93.8	41.3	6.92
DC	1	321	1430	29.03	93.9	41.2	7.88
DC	1	182	1300	33.69	94.8	41	6.62
DC	1	339	1250	27.26	92.8	36.4	7.15
DC	1	358	1510	27.80	92.7	44.1	10.97
DC	2	207	1360	33.85	91.6	28.7	6.83
DC	2	328	1420	24.30	93.5	38.4	7.95
DC	2	180	1240	27.37	92.9	34.3	6.55
DC	2	385	1450	26.74	94.1	43.8	9.09
DC	2	366	1590	30.84	91.6	44.3	6.76
40	1	313	1470	41.64	93.5	35.1	7.54
40	1	187	1140	41.18	92.9	32.9	5.20
40	1	189	1200	45.73	91.7	39	9.00
40	1	94	1060	39.16	86.1	24.9	8.52
40	1	277	1640	39.18	94.8	27.9	6.32
40	2	309	1580	41.83	93.8	36.8	9.07
40	2	199	1160	45.57	92.3	37.6	9.39
40	2	197	1360	33.32	90.6	38.5	8.81
40	2	103	1340	37.57	83.2	40.9	10.57
40	2	362	1110	33.65	93.4	33.9	8.49
50	1	114	1040	50.58	93.1	35.8	8.67
50	1	418	1610	38.57	93.4	44.8	12.65
50	1	117	1180	59.00	91.6	32.4	8.29
50	1	417	1540	50.45	92.9	43.6	13.79
50	1	403	1580	46.05	93.3	43	14.73
50	2	116	1250	47.26	93.1	38	9.99
50	2	427	1520	51.19	93.5	47.9	13.34
50	2	169	1350	40.11	94.8	41.9	7.80
50	2	416	1660	38.83	90	43.9	17.26
50	2	368	1430	42.78	94.4	34.3	8.77
HAY	1	140	1100	84.22	93	38.6	7.05
HAY	1	227	940	83.62	95.2	38.8	7.76
HAY	1	131	970	85.73	94.2	40.1	8.66
HAY	1	215	980	83.96	94.9	39.1	9.54
HAY	1	228	960	87.53	95.4	38.7	6.92
HAY	2	133	980	85.49	92.5	42.1	10.05
HAY	2	149	970	82.75	94.3	37.3	7.68
HAY	2	257	940	85.78	95.1	41.3	7.33
HAY	2	217	920	87.10	93.8	40.8	7.79
HAY	2	255	890	84.13	95.2	38.5	9.75

Table A.34. Analysis of Variance of Forage Characteristics. Cow Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	4	17767	0.0001
	Error	35	608.64	
Organic matter, %DM				
	Trt	4	49.98	0.0205
	Error	35	157.50	
Crude protein, %DM				
	Trt	4	92.04	0.0006
	Error	35	145.01	
IVOMD, %				
	Trt	4	200.80	0.0293
	Error	35	695.79	

[a] Type III sum of squares.

Table A.35. Forage Intake. Cow Experiment 1

TRT	PEN	HFWT	FFWT	FPDM	WTBK	WAST	DMNCN	DMFED	DML
DC	1	40020	50500	27.80	3640	228	1070	14034	1.60
DC	2	42420	51300	26.42	2700	220	772	13554	1.62
40	1	49440	49200	36.65	4260	265	1658	18029	1.47
40	2	45600	42770	42.02	3240	255	1469	17971	1.42
50	1	37640	36760	47.93	1475	235	820	17617	1.33
50	2	34380	37430	48.17	2040	185	1072	18030	1.03
HAY	1	24520	23380	83.66	2060	190	1882	19558	0.97
HAY	2	24450	22200	82.98	1555	180	1440	18422	0.98

TRT	PEN	DMCON	NAN	DYBL	TFDY	DDMIN	AFWT
DC	1	12965	418	91	1001	12.95	1094
DC	2	12783	418	92	1012	12.63	1062
40	1	16371	385	92	1012	16.18	1159
40	2	16502	319	91	1001	16.49	1144
50	1	16797	308	95	1045	16.07	1089
50	2	16958	308	92	1012	16.76	1070
HAY	1	17676	308	93	1023	17.28	1133
HAY	2	16983	297	92	1012	16.78	1088

Table A.36. Analysis of Variance of Forage Intake.
Cow Experiment 1

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	3501.41	0.0001
	Error	4	15.62	
Dry matter intake, kg/day				
	Trt	3	4.58	0.0008
	Error	4	0.09	
Dry matter intake, % BW				
	Trt	3	0.16	0.0001
	Error	4	0.01	
Average full weight, kg				
	Trt	4	1470	0.0717
	Error	5	373.96	

[a] Type III sum of squares.

Table A.37. Forage Intake. Cow Experiment 2

TRT	PEN	FPDM	HFWT	FFWT	WTBK	WAST	FNCN	FCON
DC	1	30.22	76840	71580	4030	510	4540	67040
DC	2	28.98	70000	67410	3515	680	4195	63215
40	1	42.22	55540	54140	3815	795	4610	49530
40	2	37.99	58860	56800	4105	735	4840	51960
50	1	48.07	55410	53240	2745	2240	4985	49775
50	2	41.67	53670	53400	4885	710	5595	49085
HAY	1	84.03	29890	28520	2050	410	2460	26980
HAY	2	85.78	20420	24940	1290	480	1770	23170

TRT	PEN	DMCON	NAN	DYBL	TFDY	DDMIN	AFWT
DC	1	20260	11	95	1045	19.39	1058
DC	2	18318	11	92	1012	18.10	1075
40	1	20911	11	88	968	21.60	1052
40	2	19740	11	92	1012	19.51	1117
50	1	23928	11	101	1111	21.54	1072
50	2	20453	11	91	1001	20.43	1108
HAY	1	22672	11	91	1012	22.40	1096
HAY	2	19875	11	94	1034	19.22	1145

Table A.38. Analysis of Variance of Forage Intake.
Cow Experiment 2

Characteristic	Source	df	Sum of Squares[a]	P
Dry matter, %				
	Trt	3	3517	0.0001
	Error	4	31.73	
Dry matter intake, kg/day				
	Trt	3	1.32	0.4841
	Error	4	1.79	
Dry matter intake, %BW				
	Trt	3	0.030	0.8148
	Error	4	0.140	
Average full weight, kg				
	Trt	3	622.27	0.4851
	Error	4	844.72	

[a] Type III sum of squares.

Table A.39. Cow Performance. Cow Experiment 1

TRT	PEN	AN	DMAG	CWT1	CWT2	CWT3	CWT4	CWT5	CWT6
DC	1	0942	9	1400	1455	1425	1435	1470	1385
DC	1	0117	7	1150	1180	980	955	945	975
DC	1	0166	7	1070	1135	960	885	920	1120
DC	1	0250	6	1285	1335	1270	1175	1155	1090
DC	1	0279	6	920	950	950	920	1180	1170
DC	1	5812	5	1090	1140	1035	970	955	980
DC	1	0425	4	1255	1300	1215	1030	1035	1070
DC	1	0568	3	1300	1360	1350	1305	1195	1225
DC	1	0572	3	925	1000	930	920	975	910
DC	1	0524	3	1000	880	885	875	840	865
DC	2	3311	5	1060	1007	1060	905	1040	990
DC	2	9069	9	1175	1270	1225	1165	1175	.
DC	2	0024	8	1120	1185	1095	980	1000	975
DC	2	0505	7	1100	1010	935	870	905	.
DC	2	0215	6	1145	1155	1170	1105	1175	1045
DC	2	0251	6	1340	1330	1080	950	1020	1100
DC	2	5819	5	1190	1060	1065	1020	1150	.
DC	2	0280	4	1070	1040	1040	840	900	1005
DC	2	0519	3	1140	1055	1000	890	950	985
DC	2	0530	3	1180	1180	1190	995	995	1325
40	1	0749	11	1170	1355	1230	1150	1125	1145
40	1	0218	8	1060	1155	1085	1040	1030	1145
40	1	0257	6	1040	1120	900	910	850	940
40	1	0290	6	1420	1480	1330	1290	1255	1265
40	1	0425	6	995	1075	1010	1045	1100	1070
40	1	0330	5	945	1000	975	1060	1020	990
40	1	0385	5	1635	1775	1665	1465	1470	1490
40	1	0427	4	1230	1335	1260	1150	1110	1105
40	1	0535	3	1140	1185	1160	1075	1095	1025
40	1	0582	3	1135	1225	1200	1220	1100	1115
40	2	0918	9	1065	1195	1135	1140	1120	1005
40	2	0051	8	1445	1415	1271	1220	1225	1220
40	2	0139	7	1135	1190	1225	1115	1150	1075
40	2	0234	6	1265	1315	1355	1260	1165	1175
40	2	0309	5	1095	1145	1075	1060	1010	1085
40	2	0371	5	1060	1120	1140	1045	1015	1110
40	2	0385	5	1395	1440	1430	1300	1470	1245
40	2	0508	4	1115	1050	1025	1000	990	1040
40	2	0526	3	1005	885	871	870	1000	935
40	2	0585	3	1155	1195	1246	1115	1120	1065
50	1	0731	11	1040	1040	1000	975	1085	1060
50	1	0005	8	1135	1170	1025	1040	1020	1045
50	1	0127	7	1230	1200	1100	1060	1045	1065
50	1	0026	6	1060	1100	1085	960	1095	1000
50	1	0296	6	1450	1500	1495	1350	1350	1480
50	1	0192	5	1100	1095	975	815	870	920
50	1	0459	4	1165	1250	1210	1050	1065	1105
50	1	0490	4	1280	1280	1205	1093	1165	1080
50	1	0557	3	1105	980	915	845	960	970
50	1	5117	3	1110	1075	940	900	930	995

Table A.39. "Continued"

50	2	0548	13	1115	1110	1000	930	1060	1100
50	2	0055	8	1060	1170	1150	1010	1080	1020
50	2	0128	7	1120	1115	1095	1015	1155	1300
50	2	2105	6	1165	1165	1025	975	965	1095
50	2	0320	5	1080	1100	995	920	1035	1015
50	2	0389	5	1165	1245	1210	1100	1110	1065
50	2	5826	5	1200	1240	1225	1045	1110	1125
50	2	0414	4	1190	1170	1210	1140	1200	1175
50	2	0518	3	1170	1045	990	945	950	930
50	2	0528	3	1070	1125	1140	980	1025	1090
HAY	1	0388	12	1190	1220	1225	1165	1105	.
HAY	1	0007	8	1075	1160	1135	1080	1055	1070
HAY	1	0105	7	1280	1400	1345	1145	1115	1110
HAY	1	0203	6	1110	1160	1120	1165	1165	1235
HAY	1	0211	6	1195	1145	1045	1105	980	985
HAY	1	3139	5	1220	1350	1300	1200	1165	1140
HAY	1	5828	5	1065	1135	980	960	930	990
HAY	1	0435	4	1150	1200	1165	1070	1100	1260
HAY	1	5120	3	1160	1275	1210	1125	1085	1015
HAY	1	0569	3	1135	1175	1150	1050	920	905
HAY	2	0656	12	1125	1150	1045	1030	940	880
HAY	2	0418	8	1080	1160	1165	1005	1025	1045
HAY	2	0138	7	1150	1165	1020	1075	1000	1045
HAY	2	0230	6	1275	1390	1130	1185	1130	1230
HAY	2	0303	6	1025	1035	1035	1030	1065	1045
HAY	2	3121	5	1100	1135	1030	975	1015	1055
HAY	2	5834	5	1090	1040	1015	1025	1000	1035
HAY	2	0455	4	1020	955	950	935	920	910
HAY	2	0530	3	1305	1340	1215	1260	1260	1325
HAY	2	0548	3	1065	1110	1080	1000	1000	1100

TRT	PEN	AN	CWT7	CSC1	CSC2	CSC3	CSC4	CSC5	PRE
DC	1	0942	1450	7	7	7	7	8	1
DC	1	0117	950	6	5	4	6	5	1
DC	1	0166	1075	6	4	4	7	7	1
DC	1	0250	1200	6	7	6	6	7	1
DC	1	0279	1100	6	7	6	7	8	0
DC	1	5812	1025	5	5	4	6	7	1
DC	1	0425	1055	7	7	6	6	6	1
DC	1	0568	1170	8	7	6	6	7	1
DC	1	0572	975	5	5	5	5	6	1
DC	1	0524	955	6	5	5	6	7	1
DC	2	3311	1050	6	6	5	6	7	1
DC	2	9069	1180	6	6	5	5	.	0
DC	2	0024	1040	5	6	5	6	.	1
DC	2	0505	1000	7	7	5	5	6	.
DC	2	0215	1140	6	7	5	5	7	0
DC	2	0251	1075	8	6	5	7	6	1
DC	2	5819	.	5	6	5	6	.	0

Table A.38. "Continued"

DC	2	0280	1005	5	5	4	5	6	1
DC	2	0519	1100	6	5	5	6	6	1
DC	2	0530	1365	6	6	4	6	8	1
40	1	0749	1100	6	6	5	7	7	0
40	1	0218	.	5	6	5	7	.	0
40	1	0257	915	6	5	5	6	5	1
40	1	0290	1305	6	8	7	6	8	1
40	1	0425	1055	4	6	5	6	7	0
40	1	0330	1015	5	5	5	7	7	.
40	1	0385	1220	8	8	8	7	8	1
40	1	0427	1185	6	7	6	6	6	.
40	1	0535	1040	7	7	7	7	6	1
40	1	0582	1140	6	7	5	6	7	1
40	2	0918	1080	6	6	6	6	7	1
40	2	0051	1250	8	7	5	6	8	.
40	2	0139	1100	5	6	5	6	6	1
40	2	0234	1200	6	7	6	7	7	1
40	2	0309	1085	4	5	5	6	6	1
40	2	0371	1070	5	5	5	7	6	1
40	2	0385	1220	8	8	7	7	8	1
40	2	0508	1070	5	5	5	6	7	1
40	2	0526	900	4	4	3	5	5	.
40	2	0585	1080	6	7	6	6	6	1
50	1	0731	820	5	5	5	6	6	.
50	1	0005	1035	5	6	5	6	6	.
50	1	0127	1150	6	6	5	6	7	1
50	1	0026	.	6	6	6	6	.	1
50	1	0296	1475	6	7	7	7	9	.
50	1	0192	1010	6	5	5	6	7	1
50	1	0459	1185	5	7	5	6	7	1
50	1	0490	1115	7	7	6	6	7	1
50	1	0557	985	5	5	5	6	6	.
50	1	5117	950	5	5	3	6	5	1
50	2	0548	1275	5	5	4	6	7	0
50	2	0055	1040	6	7	5	6	6	1
50	2	0128	.	6	5	5	7	.	.
50	2	2105	1070	6	6	5	6	6	1
50	2	0320	985	7	6	5	6	6	0
50	2	0389	995	6	6	5	6	6	.
50	2	5826	1165	5	5	4	6	6	.
50	2	0414	1180	6	7	5	6	7	1
50	2	0518	980	6	7	5	6	6	0
50	2	0528	1110	7	7	5	7	7	1

Table A.40. Analysis of Variance of Cow Performance. Cow Experiment 1

Performance	Source	df	Sum of Squares[a]	P
Winter weight change, kg				
	Trt	3	3.38	0.0831
	Pen(Trt)	4	0.95	0.1985
Summer weight change, kg				
	Trt	3	5.33	0.0760
	Pen(Trt)	4	1.41	0.1450
Winter+ summer weight change, kg				
	Trt	3	0.04	0.7246
	Pen(Trt)	4	0.10	0.5420
Initial body condition score				
	Trt	3	0.84	0.5740
	Pen(Trt)	4	1.48	0.7851
Winter change				
	Trt	3	11.10	0.0732
	Pen(Trt)	4	2.86	0.3248
Summer change				
	Trt	3	8.85	0.0280
	Pen(Trt)	4	1.26	0.8083
Pregnancy rate, %				
	Trt	3	0.01	0.9989
	Pen(Trt)	4	1.44	0.0812

[a] Type III sum of squares.

Table A.41. Calf Performance. Cow experiment 1

TRT	PEN	DAM	DMAG	CALF	SEX	BWT	DCL	CW1	CW2	CW3	CW4	CFWT
DC	1	942	9	213	1	90	496	.	.	.	95	265
DC	1	117	7	86	3	84	393	.	105	141	285	475
DC	1	166	7	99	1	70	398	.	85	120	290	505
DC	1	250	6	117	3	60	407	.	.	119	330	590
DC	1	279	6	41	5	85	368	91	181	270	445	720
DC	1	812	5	63	5	76	372	.	125	184	305	545
DC	1	425	4	112	1	80	406	.	.	114	.	.
DC	1	568	3	183	2	96	439	.	.	.	255	470
DC	1	572	3	58	1	90	465	.	.	.	.	400
DC	1	524	3	.	3	104	369	.	160	197	315	600
DC	2	3311	5	135	5	66	413	.	.	100	280	480
DC	2	9069	9	53	5	106	458	.	.	.	.	410
DC	2	024	8	.	5	80	379	.	119	165	330	560
DC	2	505	7	26	3	60	346	.	140	185	375	610
DC	2	215	6	207	1	80	481	.	.	.	130	360
DC	2	251	6	53	3	80	369	81	188	245	450	635
DC	2	5819	5	17	5	55	346	.	.	.	.	.
DC	2	280	4	122	1	70	409	.	.	100	270	505
DC	2	519	3	25	5	85	358	105	151	185	330	520
DC	2	530	3	174	5	72	433	.	.	.	180	440
40	1	749	11	140	3	68	414	.	.	.	250	450
40	1	218	8	17	6	88	414	.	.	.	.	375
40	1	257	6	.	3	62	384	.	115	159	315	515
40	1	290	6	67	5	72	373	.	145	195	390	620
40	1	425	6	133	2	82	413	.	.	114	295	505
40	1	330	5	210	3	72	493	.	.	.	110	380
40	1	385	5	132	3	92	413	.	.	167	370	600
40	1	427	4	120	5	72	407	.	.	135	290	500
40	1	535	3	153	5	76	423	.	.	107	250	460
40	1	582	3	180	1	90	435	.	.	.	235	460
40	2	918	9	197	2	72	461	.	.	.	155	355
40	2	051	8	102	1	84	398	.	.	165	365	620
40	2	139	7	129	3	82	412	.	.	115	255	445
40	2	234	6	106	1	90	405	.	.	155	360	630
40	2	309	5	58	3	83	370	.	149	195	335	510
40	2	371	5	143	3	80	417	.	.	120	280	500
40	2	385	5	132	3	92	413	.	.	167	370	600
40	2	508	4	54	5	60	369	60	127	177	320	520
40	2	526	3	30	5	61	390	90	160	212	360	555
40	2	585	3	158	5	80	427	.	.	98	285	525
50	1	731	11	201	1	72	467	.	.	.	130	330
50	1	005	8	90	5	52	395	.	65	80	175	365
50	1	127	7	33	5	87	392	80	155	190	345	545
50	1	026	6	134	5	68	413	.	.	93	240	450
50	1	296	6	118	3	75	407	.	105	110	285	530
50	1	192	5	97	5	80	394	.	.	128	272	505
50	1	459	4	137	5	92	414	.	.	155	315	540
50	1	490	4	139	5	85	414	.	.	116	210	405
50	1	557	3	51	5	72	368	77	145	194	365	575
50	1	5117	3	52	1	50	368	75	150	193	365	600

Table A.41. "Continued"

50	2	548	13	75	5	62	378	.	85	115	200	350
50	2	055	8	147	1	.	.	.	.	78	.	455
50	2	128	7	20	1	92	415	.	.	.	.	490
50	2	2105	6	.	5	80	373	.	147	168	320	480
50	2	320	5	74	5	68	378	.	92	130	230	395
50	2	389	5	165	2	72	430	.	.	80	220	400
50	2	5826	5	136	3	100	414	.	.	130	305	565
50	2	414	4	133	5	82	413	.	.	114	295	505
50	2	518	3	12	5	80	349	103	147	190	320	560
50	2	528	3	171	5	62	432	.	.	66	180	400
HAY	1	388	12	177	1	64	433	.	.	64	235	500
HAY	1	007	8	151	1	80	422	.	.	106	280	545
HAY	1	105	7	121	3	88	409	.	.	159	325	565
HAY	1	203	6	65	1	102	480	.	.	.	.	435
HAY	1	211	6	50	5	70	368	105	175	215	365	565
HAY	1	3139	5	129	3	82	412	.	.	115	255	445
HAY	1	5828	5	70	5	80	377	.	135	184	330	540
HAY	1	435	4	112	.	.	.	.	.	.	.	.
HAY	1	5120	3	144	5	88	417	.	.	124	287	555
HAY	1	569	3	116	3	110	407	.	.	168	345	590
HAY	2	656	12	110	5	68	406	.	.	108	220	370
HAY	2	418	8	148	3	80	400	.	.	105	230	420
HAY	2	138	7	76	3	84	378	.	120	155	300	525
HAY	2	230	6	77	3	90	378	.	175	228	395	625
HAY	2	303	6	206	1	68	476	.	.	.	120	330
HAY	2	3121	5	156	3	92	425	.	.	110	250	480
HAY	2	5834	5	49	5	65	368	80	122	145	285	480
HAY	2	455	4	48	5	60	368	70	130	167	305	535
HAY	2	530	3	95	5	74	402	.	.	115	210	395
HAY	2	548	3	162	2	58	459	.	.	60	205	440

Table A.42. Analysis of Variance of Calf Performance. Cow Experiment 1

Performance	Source	df	Sum of Squares[a]	P
Winter weight change, kg				
	Trt	3	0.24	0.3722
	Pen(Trt)	4	0.16	0.3579
Summer weight change, kg				
	Trt	3	0.09	0.4791
	Pen(Trt)	4	0.12	0.2530
Weaning weight, kg				
	Trt	3	6899	0.4299
	Pen(Trt)	4	7972	0.0657

[a] Type III sum of squares.

Table A.43. Cow Performance. Cow Experiment 2

TRT	PEN	DAM	DMAG	CWT1	CSC1	CWT2	CWT3	CWT4	CWT5	CSC4	PREG	CS2	CS3
DC	1	0308	6	955	5	975	815	920	950	4	70	7	4
DC	1	4006	3	980	5	1040	865	920	975	4	42	7	4
DC	1	6060	3	1005	6	1020	950	1000	1000	5	60	7	4
DC	1	0569	4	1025	6	1155	910	1000	1070	6	49	7	4
DC	1	6004	3	1165	6	1000	1040	985	980	5	0	7	5
DC	1	5834	6	1135	6	1055	950	1185	1165	5	77	7	4
DC	1	0519	4	1170	6	1110	900	1070	.	6	129	7	5
DC	1	0532	4	1215	7	975	930	995	1110	5	42	6	3
DC	1	0427	5	1205	6	1100	950	1120	1165	5	56	6	4
DC	1	2104	7	1240	6	1285	1000	1110	.	.	.	7	4
DC	1	0942	10	1445	.	1440	1435	1410	.	8	0	7	6
DC	2	4051	3	820	6	765	800	800	.	4	0	4	3
DC	2	0524	4	985	6	880	900	1010	1100	6	126	5	3
DC	2	0417	9	1025	6	1060	1005	1005	.	5	0	6	4
DC	2	4071	3	1005	7	980	815	965	1020	6	49	6	4
DC	2	0166	8	1175	6	1180	1025	1035	.	5	84	7	5
DC	2	0166	8	1085	7	1100	1020	1070	1040	5	140	7	3
DC	2	6046	3	1130	6	1105	1065	1000	995	5	0	7	4
DC	2	2105	7	1150	7	995	1025	1040	.	6	112	5	4
DC	2	0596	4	1175	6	1030	1030	1105	.	6	77	5	4
DC	2	6036	3	1270	7	1265	1350	1245	1250	6	60	7	5
DC	2	0347	6	1455	7	1340	1330	1435	1450	7	126	7	4
40	1	6030	3	990	7	990	945	875	845	4	60	7	3
40	1	4019	3	990	6	1025	935	895	.	4	0	7	4
40	1	0496	5	1160	6	1040	1190	1195	1230	7	84	6	5
40	1	5818	6	1010	6	900	795	935	1020	5	70	5	3
40	1	0557	4	1035	6	940	815	970	1060	5	56	6	3
40	1	4075	3	1090	5	1025	860	1040	.	6	42	7	3
40	1	4041	3	1120	6	1120	930	1040	.	5	70	7	5
40	1	0316	6	1210	7	1215	1110	.	.	.	.	7	4
40	1	0344	6	1170	6	1225	980	1110	1160	6	98	7	5
40	1	0399	6	1305	7	1225	1070	1210	1190	.	0	7	4
40	1	0051	9	1290	7	1095	1130	.	.	.	.	7	4
40	2	6026	3	930	7	980	1000	875	885	3	0	7	5
40	2	4125	3	960	6	1065	1075	985	.	4	0	5	4
40	2	0455	5	1045	6	1040	980	1000	1100	6	112	6	4
40	2	4115	3	1080	6	940	965	1035	.	4	49	4	3
40	2	0585	4	1085	6	1180	1115	1110	1150	6	84	6	4
40	2	0159	8	1150	6	1265	1145	1060	1190	6	105	7	5
40	2	0508	5	1105	6	1215	1075	1160	.	7	70	7	4
40	2	6041	3	1140	7	1180	1030	1040	.	5	70	7	6
40	2	0413	5	1320	7	1345	1135	1110	1125	4	70	7	4
40	2	0385	6	1490	9	1610	1455	1180	1155	6	55	9	6
50	1	6031	3	935	7	920	945	840	830	5	130	6	5
50	1	4110	3	940	5	925	880	895	.	5	0	7	4
50	1	4079	3	995	6	820	815	855	930	5	56	6	3
50	1	4130	3	1015	6	1055	900	975	1040	4	49	7	2
50	1	0591	4	1095	7	1185	1065	1035	.	5	0	7	4
50	1	0435	5	1390	7	1365	1225	1370	1350	7	140	7	6
50	1	8118	11	1095	6	1115	1185	1035	.	5	0	6	4
50	1	0403	5	1210	7	1130	1065	1100	1175	6	49	7	5

Table A.43. "Continued"

50	1	0425	5	1170	8	1180	1005	990	960	4	0	7	4
50	1	0537	4	1255	7	1245	1130	1195	1260	6	112	7	5
50	1	0947	10	1305	6	1285	1185	1060	1055	5	140	8	6
50	2	4012	3	930	5	920	850	845	.	3	0	5	3
50	2	5812	6	1100	6	1055	1000	1065	1100	5	77	5	3
50	2	4025	3	1020	6	1030	970	1065	1090	5	112	6	4
50	2	5828	6	1030	6	1190	1160	1205	1245	7	84	7	5
50	2	0521	4	1080	7	1120	1115	1050	1030	5	110	7	6
50	2	0918	10	1115	7	1195	1155	915	910	3	120	6	5
50	2	0138	8	1135	7	.	1160	1110	.	6	49	.	6
50	2	4030	3	1130	7	1095	1035	1130	.	6	0	7	5
50	2	0459	5	1185	7	1260	1230	1195	.	6	0	7	6
50	2	0230	7	1195	7	1315	1220	1285	1265	7	49	7	5
HAY	1	6024	3	935	7	960	965	1010	1040	6	140	6	4
HAY	1	2106	7	945	5	915	935	920	.	4	0	5	4
HAY	1	4136	3	950	5	800	875	975	.	5	0	6	3
HAY	1	4118	3	1070	7	1000	990	1015	.	4	0	6	3
HAY	1	0064	9	1110	7	1160	1110	955	.	3	42	7	5
HAY	1	4057	3	1055	6	910	975	995	1080	5	91	5	4
HAY	1	0590	4	1090	6	1000	975	1000	1060	5	98	6	4
HAY	1	0530	4	1175	7	1210	1220	1100	1075	4	70	7	4
HAY	1	5135	4	1195	7	1250	1080	1150	.	6	84	7	4
HAY	1	0290	7	1370	8	1300	1325	1390	1370	7	126	7	5
HAY	1	0301	6	1390	8	1300	1380	1340	.	7	0	7	6
HAY	2	6410	3	1185	7	1280	1270	1300	1335	7	140	7	5
HAY	2	3102	6	985	6	975	930	1000	990	5	84	6	3
HAY	2	4126	3	985	6	1070	1000	1005	1070	5	77	6	4
HAY	2	5117	4	1070	7	1175	1160	.	.	7	63	7	6
HAY	2	0535	4	1080	6	1160	1010	1030	1045	5	70	6	5
HAY	2	0211	7	1120	7	1100	1050	1015	1085	6	42	7	4
HAY	2	0536	4	1130	6	1195	1160	1005	1010	5	140	7	6
HAY	2	0421	6	1200	7	1275	1105	1220	.	6	0	7	5
HAY	2	0468	5	1245	7	1325	1175	1105	1130	5	140	7	6
HAY	2	0908	10	1325	7	1320	1270	1270	1305	6	70	6	3
HAY	2	0395	6	1400	9	1360	1320	1370	1345	7	91	8	5

Table A.44. Analysis of Variance of Cow Performance. Cow Experiment 2

Performance	Source	df	Sum of Squares[a]	P
Winter weight change, kg				
	Trt	3	2.49	0.4842
	Pen(Trt)	4	3.36	0.0009
Summer weight change, kg				
	Trt	3	0.27	0.5832
	Pen(Trt)	4	0.49	0.0316
Summer+ winter weight change, kg				
	Trt	3	0.03	0.7733
	Pen(Trt)	4	0.11	0.1263
Body condition score				
Initial				
	Trt	3	3.50	0.3213
	Pen(Trt)	4	2.91	0.3346
Winter change				
	Trt	3	1.95	0.6437
	Pen(Trt)	4	4.28	0.5027
Summer change				
	Trt	3	1.12	0.7385
	Pen(Trt)	4	3.39	0.6033
Pregnancy rate, %				
	Trt	3	0.19	0.6843
	Pen(Trt)	4	0.46	0.6823

[a] Type III sum of squares.

Table A.45. Calf performance. Cow Experiment 2

TRT	PEN	DAM	CALF	BWT	DCL	CW1	CW2	CW3	CW4	CW5	CFWT
DC	1	0308	150	68	423	.	75	120	200	355	430
DC	1	4006	135	62	416	.	95	145	210	325	415
DC	1	6060	199	62	467	.	.	65	105	220	360
DC	1	0569	112	72	410	.	100	160	245	370	455
DC	1	6004	209	60	490	.	.	.	100	215	350
DC	1	5834	43	102	367	.	175	235	320	455	520
DC	1	0519	50	84	369	130	185	260	360	510	555
DC	1	0532	28	90	346	140	235	325	490	565	660
DC	1	0427	52	124	370	245	245	350	465	640	790
DC	1	2104	68	90	388	.	150	225	320	455	525
DC	1	0942	204	72	476	.	.	.	.	.	.
DC	2	4051	12	81	391	120	250	.	385	500	585
DC	2	0524	2	42	384	84	195	195	218	420	470
DC	2	0417	80	54	395	.	175	204	350	435	510
DC	2	4071	70	78	388	.	200	220	305	410	490
DC	2	0166	74	68	391	.	200	215	300	450	580
DC	2	0166	89	76	401	.	170	190	265	385	475
DC	2	6046	134	90	416	.	150	140	300	325	430
DC	2	2105	16	104	362	140	270	270	303	400	610
DC	2	0596	29	92	365	130	275	275	305	464	625
DC	2	6036	202	62	476	.	.	.	125	255	375
DC	2	0347	7	80	358	140	305	343	525	600	710
40	1	6030	146	64	359	.	85	125	190	350	445
40	1	4019	187	86	444	.	.	125	198	320	400
40	1	0496	177	82	438	.	.	131	210	350	465
40	1	5818	11	92	360	150	190	265	366	500	575
40	1	0557	32	74	365	125	165	240	396	440	530
40	1	4075	10	60	359	135	210	309	415	525	620
40	1	4041	62	88	374	.	140	200	270	395	480
40	1	0316	.	.	.	.	.	.	.	.	.
40	1	0344	81	68	395	.	135	235	355	510	610
40	1	0399	56	82	374	110	185	280	395	555	660
40	1	0051	.	.	.	.	.	.	.	.	.
40	2	6026	4	62	386	135	210	285	390	505	605
40	2	4125	73	88	391	.	170	258	395	480	555
40	2	0455	6	60	358	100	155	235	230	445	550
40	2	4115	42	104	367	.	165	.	.	.	.
40	2	0585	106	62	407	.	100	160	245	380	445
40	2	0159	65	70	385	.	150	220	359	430	510
40	2	0508	85	58	398	.	100	160	305	365	465
40	2	6041	137	88	417	.	.	.	.	.	.
40	2	0413	121	114	411	.	140	196	270	400	530
40	2	0385	107	94	407	.	155	215	363	485	600
50	1	6031	171	90	436	.	.	105	125	245	385
50	1	4110	92	86	402	.	140	225	325	490	575
50	1	4079	15	80	361	125	190	265	410	480	565
50	1	4130	66	90	387	.	165	245	335	480	580
50	1	0591	147	80	421	.	100	179	325	420	500
50	1	0435	99	72	404	.	.	.	.	.	.
50	1	8118	178	52	439	.	.	280	135	215	290
50	1	0403	33	72	365	110	220	290	380	505	615

Table A.45. "Continued"

50	1	0425	108	84	409	.	140	225	305	445	545
50	1	0537	27	84	364	130	220	315	477	570	625
50	1	0947	159	80	427	.	70	173	250	435	555
50	2	4012	18	68	362	113	190	260	392	465	515
50	2	5812	17	48	362	60	90	135	200	300	375
50	2	4025	9	72	359	110	165	238	335	470	545
50	2	5828	172	84	436	.	.	.	.	.	.
50	2	0521	210	62	493	.	.	.	105	255	375
50	2	0918	190	88	445	.	.	129	185	292	390
50	2	0138	103	82	405	.	110	185	292	355	405
50	2	4030	1	70	405	120	185	255	325	440	510
50	2	0459	203	98	383	.	185	.	135	265	385
50	2	0230	127	62	413	.	80	135	238	395	480
HAY	1	6024	191	54	.	.	.	.	.	.	.
HAY	1	2106	19	32	362	55	110	185	245	325	365
HAY	1	4136	21	78	363	90	155	230	315	460	550
HAY	1	4118	34	80	365	110	195	265	366	520	600
HAY	1	0064	119	70	411	.	95	140	210	340	405
HAY	1	4057	3	74	353	130	200	275	355	495	565
HAY	1	0590	44	84	367	110	200	300	405	555	655
HAY	1	0530	182	80	441	.	.	110	170	275	370
HAY	1	5135	69	86	388	.	170	255	413	495	570
HAY	1	0290	35	78	365	100	210	293	395	540	640
HAY	1	0301	194	88	456	.	.	.	.	.	
HAY	2	6410			60	.	.	.	.	.	.
HAY	2	3102	22	76	363	105	195	280	370	480	575
HAY	2	4126	130	82	414	.	100	158	287	385	470
HAY	2	5117	180	60	440	.	.	120	220	395	420
HAY	2	0535	126	94	414	.	125	185	275	425	525
HAY	2	0211	48	100	368	130	200	275	305	540	645
HAY	2	0536	164	82	432	.	.	125	205	370	485
HAY	2	0421	105	80	407	.	130	208	310	450	555
HAY	2	0468	98	62	404	.	110	167	220	340	405
HAY	2	0908	5	76	354	115	185	76	260	355	515
HAY	2	0395	61	80	381	.	210	308	430	595	690

Table A.46. Analysis of Variance of Calf Performance. Cow Experiment 2

Performance	Source	df	Sum of Squares[a]	P
Winter weight change, kg				
	Trt	3	0.06	0.8436
	Pen(Trt)	4	0.29	0.2683
Summer weight change, kg				
	Trt	3	0.16	0.8075
	Pen(Trt)	4	0.62	0.0035
Weaning weight, kg				
	Trt	3	1415	0.7896
	Pen(Trt)	4	5321	0.2574

[a] Type III sum of squares.

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BIOGRAPHICAL SKETCH

Abou Berthe was born February 18, 1949, in Zerila, Region of Sikasso, Mali. In 1961, he graduated from the primary private Catholic School of Sikasso. In 1966, he received the Diploma of high school from Tieba fundamental school in Sikasso. From 1967 to 1969, he attended the Polytechnic Rural Institute of Katibougou Mali, where he received the Diploma of Livestock Husbandry Assistant. From 1972 to 1976, he pursued college studies at Polytechnic Rural Institute to receive the degree of "ingenieur des sciences appliquees." From 1982 to 1984, he attended the National School of Advanced Agricultural Studies at Toulouse and Dijon where he obtained the Diploma of Advanced Studies in Biology and Nutritional Physiology. In August 1987, he arrived in Gainesville with a scholarship Mali/USAID to continue his studies. At present he is a candidate for the degree of Doctor of Philosophy in Animal Science.

He is married to Oumou Sidibe and is the father of six children, Abdramane, Bintou, Seydou, Hamidou, Ibrahim, and Kadidia. He is member of the American Society of Animal Science and the West African Network for Farming Systems Research.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William E. Kunkle

William E. Kunkle, Chairman
Associate Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Douglas B. Bates

Douglas B. Bates, Cochair
Associate Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John E. Moore

John E. Moore
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Associate Professor of Dairy Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Thomas H. Spreen
Professor of Food and Resources Economics

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1991

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